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Model 4200A-SCS Pulse Card (PGU and PMU)

User Manual

4200A-PMU-900-01 Rev. D September 2026

4200A-PMU-900-01D

KEITHLEY
A Tektronix Company

Model 4200A-SCS

Pulse Card (PGU and PMU)

User Manual

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Safety precautions

The following safety precautions should be observed before using this product and any associated instrumentation. Although some instruments and accessories would normally be used with nonhazardous voltages, there are situations where hazardous conditions may be present.

This product is intended for use by personnel who recognize shock hazards and are familiar with the safety precautions required to avoid possible injury. Read and follow all installation, operation, and maintenance information carefully before using the product. Refer to the user documentation for complete product specifications.

If the product is used in a manner not specified, the protection provided by the product warranty may be impaired.

The types of product users are:

Responsible body is the individual or group responsible for the use and maintenance of equipment, for ensuring that the equipment is operated within its specifications and operating limits, and for ensuring that operators are adequately trained.

Operators use the product for its intended function. They must be trained in electrical safety procedures and proper use of the instrument. They must be protected from electric shock and contact with hazardous live circuits.

Maintenance personnel perform routine procedures on the product to keep it operating properly, for example, setting the line voltage or replacing consumable materials. Maintenance procedures are described in the user documentation. The procedures explicitly state if the operator may perform them. Otherwise, they should be performed only by service personnel.

Service personnel are trained to work on live circuits, perform safe installations, and repair products. Only properly trained service personnel may perform installation and service procedures.

Keithley products are designed for use with electrical signals that are measurement, control, and data I/O connections, with low transient overvoltages, and must not be directly connected to mains voltage or to voltage sources with high transient overvoltages. Measurement Category II (as referenced in IEC 60664) connections require protection for high transient overvoltages often associated with local AC mains connections. Certain Keithley measuring instruments may be connected to mains. These instruments will be marked as category II or higher.

Unless explicitly allowed in the specifications, operating manual, and instrument labels, do not connect any instrument to mains.

Exercise extreme caution when a shock hazard is present. Lethal voltage may be present on cable connector jacks or test fixtures. The American National Standards Institute (ANSI) states that a shock hazard exists when voltage levels greater than 30 V RMS, 42.4 V peak, or 60 VDC are present. A good safety practice is to expect that hazardous voltage is present in any unknown circuit before measuring.

Operators of this product must be protected from electric shock at all times. The responsible body must ensure that operators are prevented access and/or insulated from every connection point. In some cases, connections must be exposed to potential human contact. Product operators in these circumstances must be trained to protect themselves from the risk of electric shock. If the circuit is capable of operating at or above 1000 V, no conductive part of the circuit may be exposed.

Do not connect switching cards directly to unlimited power circuits. They are intended to be used with impedance-limited sources. NEVER connect switching cards directly to AC mains. When connecting sources to switching cards, install protective devices to limit fault current and voltage to the card.

Before operating an instrument, ensure that the line cord is connected to a properly-grounded power receptacle. Inspect the connecting cables, test leads, and jumpers for possible wear, cracks, or breaks before each use.

When installing equipment where access to the main power cord is restricted, such as rack mounting, a separate main input power disconnect device must be provided in close proximity to the equipment and within easy reach of the operator.

For maximum safety, do not touch the product, test cables, or any other instruments while power is applied to the circuit under test. ALWAYS remove power from the entire test system and discharge any capacitors before connecting or disconnecting cables or jumpers, installing or removing switching cards, or making internal changes, such as installing or removing jumpers.

Do not touch any object that could provide a current path to the common side of the circuit under test or power line (earth) ground. Always make measurements with dry hands while standing on a dry, insulated surface capable of withstanding the voltage being measured.

For safety, instruments and accessories must be used in accordance with the operating instructions. If the instruments or accessories are used in a manner not specified in the operating instructions, the protection provided by the equipment may be impaired.

Do not exceed the maximum signal levels of the instruments and accessories. Maximum signal levels are defined in the specifications and operating information and shown on the instrument panels, test fixture panels, and switching cards.

When fuses are used in a product, replace with the same type and rating for continued protection against fire hazard.

Chassis connections must only be used as shield connections for measuring circuits, NOT as protective earth (safety ground) connections.

If you are using a test fixture, keep the lid closed while power is applied to the device under test. Safe operation requires the use of a lid interlock.

If a  screw is present, connect it to protective earth (safety ground) using the wire recommended in the user documentation.

The  symbol on an instrument means caution, risk of hazard. The user must refer to the operating instructions located in the user documentation in all cases where the symbol is marked on the instrument.

The  symbol on an instrument means warning, risk of electric shock. Use standard safety precautions to avoid personal contact with these voltages.

The  symbol on an instrument shows that the surface may be hot. Avoid personal contact to prevent burns.

The  symbol indicates a connection terminal to the equipment frame.

If this  symbol is on a product, it indicates that mercury is present in the display lamp. Please note that the lamp must be properly disposed of according to federal, state, and local laws.

The **WARNING** heading in the user documentation explains hazards that might result in personal injury or death. Always read the associated information very carefully before performing the indicated procedure.

The **CAUTION** heading in the user documentation explains hazards that could damage the instrument. Such damage may invalidate the warranty.

The **CAUTION** heading with the  symbol in the user documentation explains hazards that could result in moderate or minor injury or damage the instrument. Always read the associated information very carefully before performing the indicated procedure. Damage to the instrument may invalidate the warranty.

Instrumentation and accessories shall not be connected to humans.

Before performing any maintenance, disconnect the line cord and all test cables.

To maintain protection from electric shock and fire, replacement components in mains circuits — including the power transformer, test leads, and input jacks — must be purchased from Keithley. Standard fuses with applicable national safety approvals may be used if the rating and type are the same. The detachable mains power cord provided with the instrument may only be replaced with a similarly rated power cord. Other components that are not safety-related may be purchased from other suppliers as long as they are equivalent to the original component (note that selected parts should be purchased only through Keithley to maintain accuracy and functionality of the product). If you are unsure about the applicability of a replacement component, call a Keithley office for information.

Unless otherwise noted in product-specific literature, Keithley instruments are designed to operate indoors only, in a non-residential location, in the following environment: Altitude at or below 2,000 m (6,562 ft); temperature 0 °C to 50 °C (32 °F to 122 °F); and pollution degree 1 or 2.

To clean an instrument, use a cloth dampened with deionized water or mild, water-based cleaner. Clean the exterior of the instrument only. Do not apply cleaner directly to the instrument or allow liquids to enter or spill on the instrument. Products that consist of a circuit board with no case or chassis (e.g., a data acquisition board for installation into a computer) should never require cleaning if handled according to instructions. If the board becomes contaminated and operation is affected, the board should be returned to the factory for proper cleaning/servicing.

Safety precaution revision as of June 2018.

Table of contents

Introduction **1**

Models 4220-PGU and 4225-PMU 1

Connections **2**

Introduction 2

Connection guidelines 2

PMU common connections 3

Shield connections 3

Cable length 4

High frequency connections 4

Prober chuck connections 4

PGU and PMU connectors 5

Model 4225-RPM 5

RPM input, output, and top panels 6

Connecting the RPM to the PMU 7

Mounting the RPM 8

RPM diagrams for local and remote sensing 9

Using the RPM as a switch 9

Two-terminal device connections 10

Three-terminal device connections 12

Four-terminal device connections 13

Pulse source-measure connections 15

Pulse generator connections 15

Using an adapter cable to connect pulse card to DUT 16

Connections to prober or test fixture bulkhead connectors 16

RPM connections to DUT 17

Two-terminal test connections 17

Remote sensing using RPM connections to a prober 18

PMU connection compensation 20

Short compensation 20

Offset current compensation 21

Perform connection compensation 21

Enabling connection compensation 22

Load-line effect compensation (LLEC) for the PMU 23

Methods to compensate for load-line effect 25

How LLEC adjusts pulse output to the target levels 25

Coping with the loadline effect 27

LLEC maintains even voltage spacing 28

Test considerations 29

LPT functions used to configure LLEC 29

Enable LLEC 30

Disable LLEC and set the output impedance 31

Setting up PMUs and PGUs in Clarius 32
Introduction 32
Configure the PGU, PMU, and RPM using tests 32
Create a PMU project 33
Configure the tests 33
PMU operation modes 36
PMU - all terminal parameters 37
Start (PMU Amplitude Sweep) 37
Stop (PMU Amplitude Sweep) 38
Step (Pulse Amplitude Sweep) 38
Points 38
Base 38
Amplitude 38
Dual Sweep (pulse) 39
Force Range (PMU) 39
Disable outputs at completion 39
Current Spot Mean High 40
Current Spot Mean Low 40
Measure Current Range (PMU) 40
Low Range 41
Current Sample Waveform 42
Voltage Spot Mean High 42
Voltage Spot Mean Low 42
Voltage Sample Waveform 42
Report Timestamps 42
Report Status (PMU) 43
PMU measurement status 43
Compensation Short Connection 46
Load Line Effect Compensation 46
DUT Resistance (R DUT) 46
Max Voltage Estimator 46
Threshold Current 46
Threshold Voltage 47
Threshold Power 47
PMU Test Settings 47
Pulse Settings 47
Timing Parameters 51
PMU Advanced Test Settings 54
PMU capacitive charging/discharging effects 64
PMU and RPM measure ranges are not source ranges 67
4220-PGU and 4225-PMU output limitations 68
Configure the PGU, PMU, and RPM using tests 68
Step or sweep multiple device terminals in the same test 68
Basic troubleshooting procedure 71
Step 1. Verify prober connections from the PMU or RPM to the DUT 71
Step 2. Verify the pulse shape 72
Step 3. Is the pulse level correct for each channel? 73
Step 4. Is the pulse I-V curve suspect? 73

Pulse card concepts 78
Models 4220-PGU and 4225-PMU 78

PMU block diagram ... 79
Pulse modes ... 79
Pulse measurement types (PMU) ... 80
Measure modes ... 80

4200A-SCS power supply limitations ... 81

Pulse source-measure concepts ... 84
Ultra-fast I-V tests ... 84
Sample rate ... 86
Segment Arb waveform ... 88
Full arb waveform ... 90
Pulse waveforms for nonvolatile memory testing ... 91
Waveform capture number of samples ... 92
DUT resistance determines pulse voltage across DUT ... 92
Triggering ... 97

Measurement types ... 100
Spot mean measurements ... 101
Spot mean discrete readings ... 101
Spot mean average readings ... 102
Waveform measurements ... 102
Waveform discrete readings ... 103
Waveform average readings ... 104
Measurement timing ... 104

KPulse (for Keithley Pulse Cards) ... 108

Keithley Pulse Application ... 108
Starting KPulse ... 108
KPulse setup and help ... 109

Triggering ... 110

Standard pulse waveforms ... 110

Segment Arb waveforms ... 112
Exporting Segment Arb waveform files ... 114

Custom file arb waveforms (full arb) ... 115
Custom Arb file operation: Select and configure waveforms ... 116
Custom Arb file operation: Copy waveforms into Sequencer ... 117
Custom Arb file operation: Load waveform and turn on output ... 119
Waveform types ... 120

Use the RPM to switch the SMU, CVU, and PMU ... 127

Introduction ... 127

Included accessories ... 128

Equipment required ... 129

Update the RPM configuration in KCon ... 129

Device connections ... 130
Connection schematic ... 130
Connect the 4200A-SCS to the DUT ... 131

Set up the measurements in Clarius ... 132
Create a new project ... 132
Add a device ... 133
Search for and select existing tests in the Test Library ... 134
Configure the vfd test ... 135
Configure the cv-diode test ... 137

Configure the pulse-diode test 139
Run the test 140
View and analyze the test results 141

PMU for pulse I-V measurements on a MOSFET 143

Introduction 143

Equipment required 143

Device connections 144
Connection schematic 144

Set up the measurements in Clarius 146
Create a new project 146
Search for and select an existing test 147
Configure the test 148
Run the test and analyze the results 150

Testing flash memory 151

Testing flash memory 151

Flash connection guidelines 152
Programming and erasing flash memory 153

Endurance testing 158
Connections for endurance testing - no switching matrix 159
Connections for endurance testing - switching matrix 161

Disturb testing 162
Connections for disturb testing 162

Using a switching matrix 164

Use KPulse to create and export Segment Arb waveforms 164

Enter Segment Arb values into UTM array parameters 166

Direct connections to single DUT 167

Direct connections to array DUT for disturb testing 169

Section 1

Introduction

Models 4220-PGU and 4225-PMU

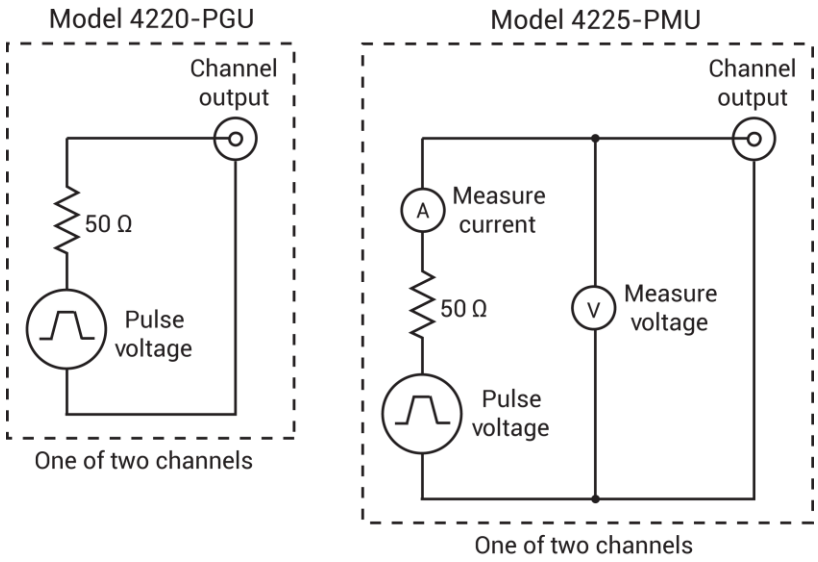
The 4220-PGU High Voltage Pulse Generator Unit and 4225-PMU Ultra-Fast Pulse Measure Unit are high-speed pulse-generator cards for the 4200A-SCS. The 4220-PGU provides pulse output only. The 4225-PMU provides both pulse output and pulse measurement. The PGU and PMU have similar pulse output characteristics.

The 4225-PMU can be paired with one or two 4225-RPM Remote Preamplifier/Switch Modules. The RPM is a remote amplifier and automatic switch. When the RPM is used as a preamplifier for the PMU, it provides additional low-current measurement ranges. When the RPM is used as a switch, it switches between the PMU, SMUs, and CVUs.

LPT functions that pertain to the PGU and PMU are documented in “LPT commands for PGUs and PMUs” in *Model 4200A-SCS LPT Library Programming*.

To do quick tests with minimal interaction with other 4200A-SCS test resources, you can use the Keithley Pulse Application (KPulse). KPulse is a nonprogramming alternative that you can use to configure and control the installed Keithley pulse cards. Refer to KPulse (on page 108) for additional information.

The simplified circuits of the 4220-PGU and 4225-PMU pulse generators are shown in the following figure.



Section 2

Connections

Introduction

Proper connection methods are critical to perform stable and accurate measurements using the PMU, with or without the RPM. The guidelines in this chapter help prevent pulse voltage overshoot and oscillations.

You can use the Multi-measurement Prober Cable Kits (4210-MMPC) to connect the 4200A-SCS to perform pulse I-V measurements. These kits help maximize signal fidelity by eliminating the measurement errors that often result from cabling errors. The prober cable kits include:

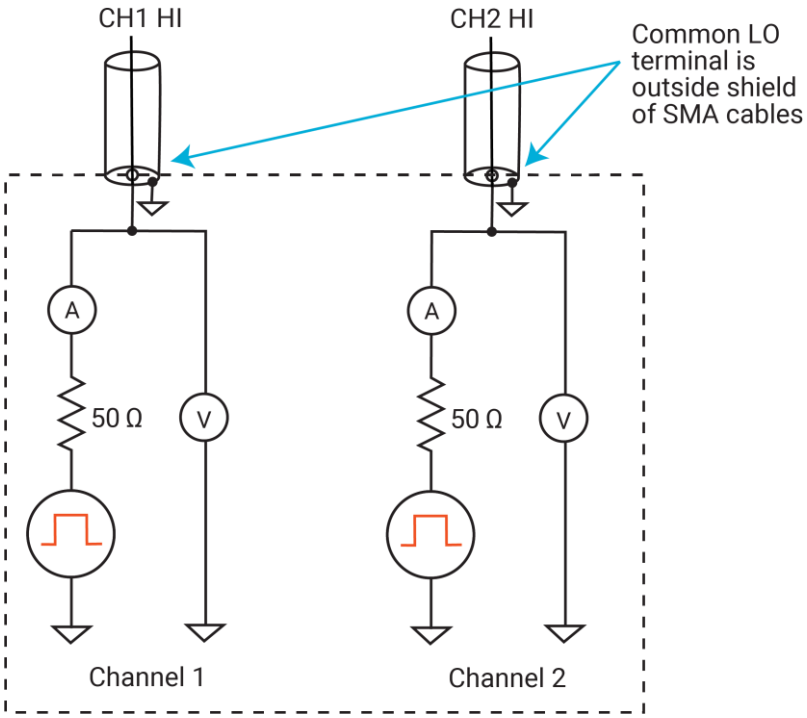
- 4210-MMPC-C Multi-Measurement (I-V, C-V, Pulse) Prober Cable Kit for Cascade Microtech 12000 prober series
- 4210-MMPC-S Multi-Measurement (I-V, C-V, Pulse) Prober Cable Kit for SUSS MicroTec PA200/300 prober series
- 4210-MMPC-L Multi-Measurement (I-V, C-V, Pulse) Prober Cable Kit for Lucas Signatone probers
- 4210-MMPC-W Multi-Measurement (I-V, C-V, Pulse) Prober Cable Kit for Wentworth Laboratories probers

Connection guidelines

The following guidelines describe PMU common connections, shield connections, cable length, high frequency connections, and prober chuck connections for the PMUs and PGUs.

PMU common connections

Common LO for the PMU is the outer shells of the two SMA connectors. With an SMA cable connected, as shown in the following figure, common LO is the outside shield of the cable.



Because pulsing requires high frequency signal propagation, reduce cable inductance by minimizing the loop area of the connection to the device under test (DUT).

Do not use the GNDU as common low for the PMU to avoid creating a large loop area. When using the GNDU, an inductive loop area is created when the HI and LO leads are separated. Fast rise times (dt), high current (di), and large inductances (L) can cause voltage overshoots, oscillations, and ringing in the high-speed measurement circuit. This is based on Lenz's law: V = L di/dt.

Shield connections

For multiple PMU channels, you should connect the shields (common LO) from all PMU channels as close as possible to the DUT. You reduce inductance by minimizing the loop area of the shield connections. The figure in Using an adapter cable to connect pulse card to DUT (on page 16) and the Local sensing (on page 17) figures illustrate proper shield connection schemes using the supplied cabling.

Cable length

Use the shortest possible cable length to achieve the highest frequency output, the best pulse shape, and the best results. Here are reasons to avoid using longer cable lengths:

- Longer cable lengths have longer reflection times, which can slow down transmission times.
- Longer cables may have impedance mismatches, which can cause distortions.
- Higher capacitance in longer cables causes higher capacitive charging effects during the pulse transitions (see PMU capacitive charging/discharging effects (on page 64)).

Only use the white SMA coaxial cables that are supplied with the PMU and RPM. These are 50 Ω cables that match the internal 50 Ω resistance of the PMU. The PMU is supplied with 6.5 ft (2 m) SMA cables and the RPM is supplied with 8 in. (20 cm) SMA cables. Always use the 8 in. (20 cm) SMA cables with the RPM.

High frequency connections

Use these connection guidelines for high-speed testing (pulse width <1 µs).

- Use cables and connectors optimized for high frequency (at least 150 MHz). The SMA coaxial cables supplied with the PMU and RPM are rated for high frequency.
- Probe manipulators must be rated at least 150 MHz.
- Properly connect the shields of the coaxial cables and minimize the loop area of the shield connections (see Shield connections (on page 3)).
- Minimize cable length (see Cable length (on page 4)).
- Use a signal path that matches the impedance of the instrument (50 Ω). The SMA cables supplied with the PMU and RPM are 50 Ω.

Prober chuck connections

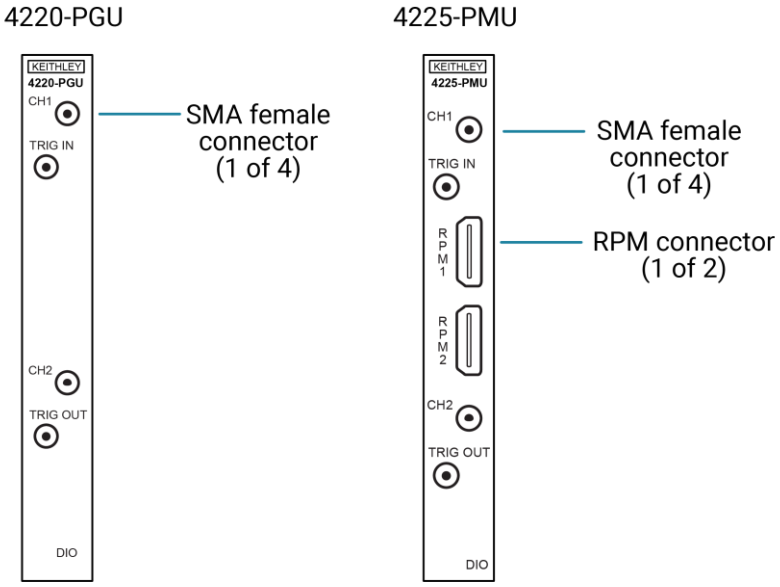
When possible, avoid pulse connections to the prober chuck. If unavoidable, use these guidelines when connecting to the prober chuck:

- When making connections to the back side of the wafer, PMU functionality will be diminished. Use caution and verify waveforms.
- Generally, the chuck adds capacitance and noise. This reduces both low-current and high-speed sampling performance.
- If one of the device terminals is the back side of the wafer, then pulse only on that terminal (on chuck) and measure at another terminal using the second channel. If possible, do not measure from the PMU channel connected to the chuck.

- For a two-terminal device, refer to Two-terminal device connections (on page 10), using figure "Two-terminal device connections to a PMU using both channels" as a guide.
- For a four-terminal device, use the Four-terminal device connections (on page 13) to two PMUs figure, or the Local sensing (on page 17) four-terminal figure as a guide (as applicable). This cabling approach permits the low-side measurement approach described in PMU capacitive charging/discharging effects (on page 64).

PGU and PMU connectors

The connectors for the PGU and PMU pulse cards are shown in the following figure.



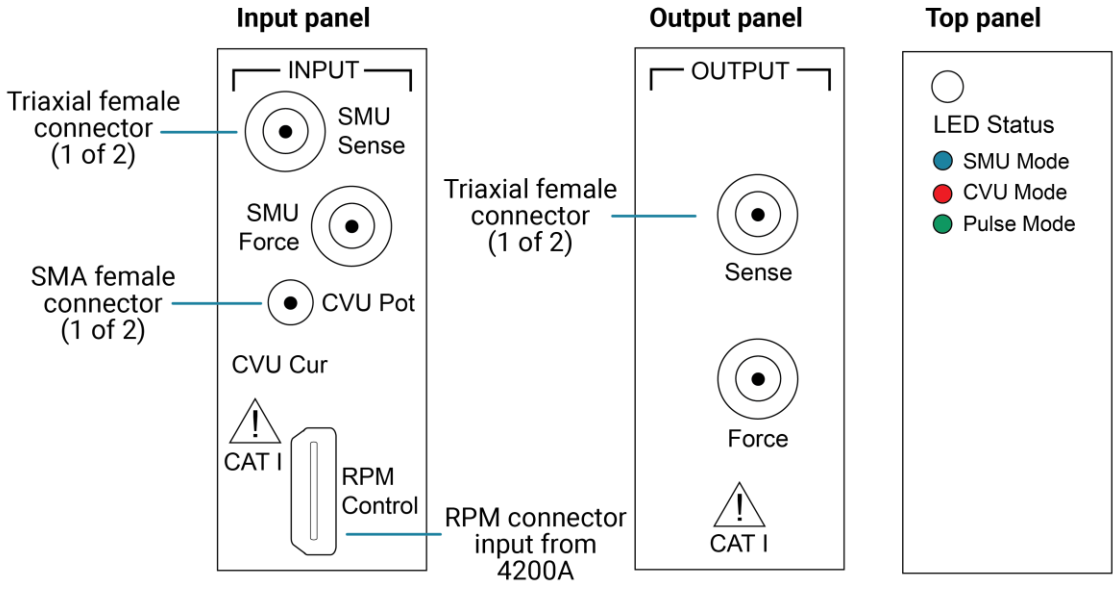
Model 4225-RPM

The 4225-RPM is a remote amplifier/switch that is used as a current preamplifier for the 4225-PMU. The RPM provides additional high-speed, low-current measurement ranges.

The RPM can also be used as a switch for the 4200-SMU, 4201-SMU, 4210-CVU, and 4215-CVU. See Using the RPM as a switch (on page 9).

RPM input, output, and top panels

The input, output, and top panels for the RPM are shown in the following figure.



The RPM connector on the input panel connects to one of the RPM connectors (channel 1 or channel 2) on the 4225-PMU. The RPM also has input connectors for a 4200-SMU or 4201-SMU (source-measure unit) and a 4210-CVU or 4215-CVU (capacitance-voltage unit).

The previous figure shows modes for the RPM LED colors. During normal Clarius operation, only the red, green, or blue lights are shown. However, other colors or color combinations are possible. For example, during the 4225-PMU self-test, the RPM LED alternates between purple and green for the majority of the test, but there is a portion of the test where the LED flashes red and green. During firmware upgrade of the 4225-PMU, the RPM LED is green, but flashes red and green near the end of the process. During firmware upgrade of the 4225-RPM, the RPM LED is blue at the start, and changes to green for the remainder of the process.

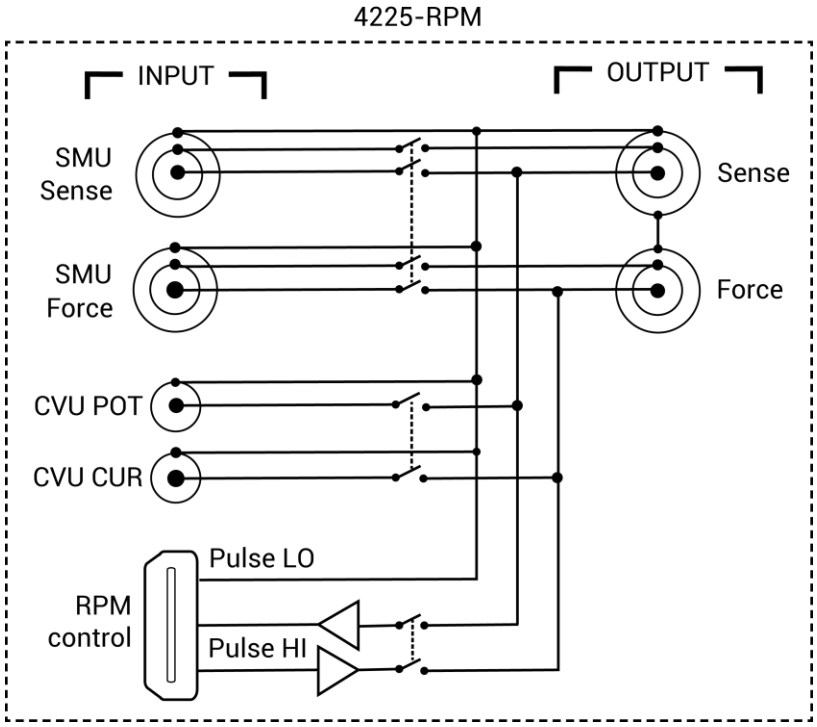
The output status of the 4200A-SCS is indicated by the Operate light on the front of the 4200A-SCS chassis.

RPM wiring diagram

The internal wiring diagram of the RPM is shown in the following figure.

Signals from the 4200A-SCS instrument cards are routed through the RPM to the output Force and Sense connectors. Switching is used to control which card is connected to the output. See Using the RPM as a switch (on page 9) for more information on switching.

The LEDs on the top panel (see the previous figure) indicate which card is connected to the output. By default, the RPM (pulse mode) is connected to the output unless a SMU or CVU is switched in.



Connecting the RPM to the PMU

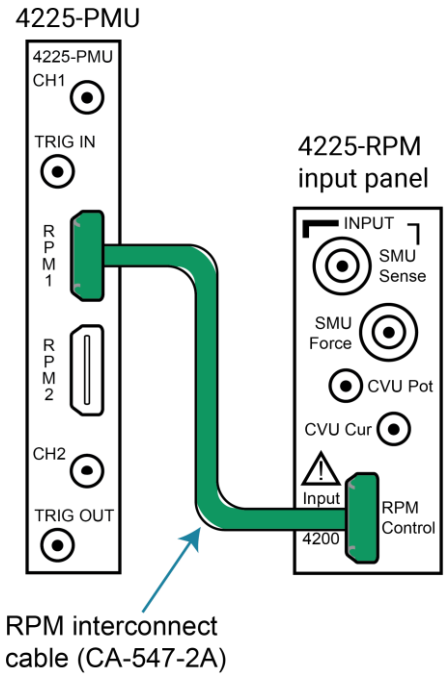
CAUTION

Turn off the system and disconnect the power cord before connecting or disconnecting the RPM to or from the PMU. Failure to do so may result in RPM or PMU damage, possibly voiding the warranty.

NOTE

The RPM is matched to a PMU card and channel. Make sure to connect the RPM only to that PMU card and channel. Labels on top of the RPM indicate the specific connection channel and PMU. For example, "PMU1-2" indicates PMU1, channel 2.

With system power off, use the supplied RPM cable to connect a 4225-RPM to the matching RPM channel of the 4225-PMU, as shown in the following figure.



CAUTION

With an RPM installed, never make connections directly to any of the SMA connectors (CH1 and CH2) on the PMU. This may result in damage to the PMU or DUT. It may also produce corrupt data.

NOTE

After connecting or removing an RPM, always perform the procedure “Update the RPM configuration” in *Model 4200A-SCS Setup and Maintenance* to ensure that KCon accurately represents the present 4200A-SCS hardware configuration.

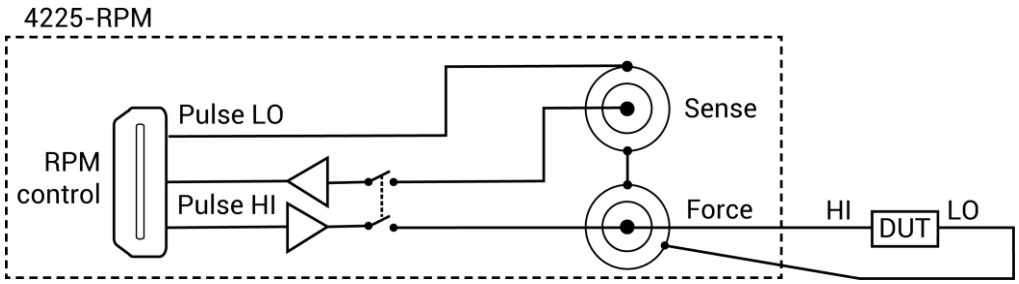
Mounting the RPM

CAUTION

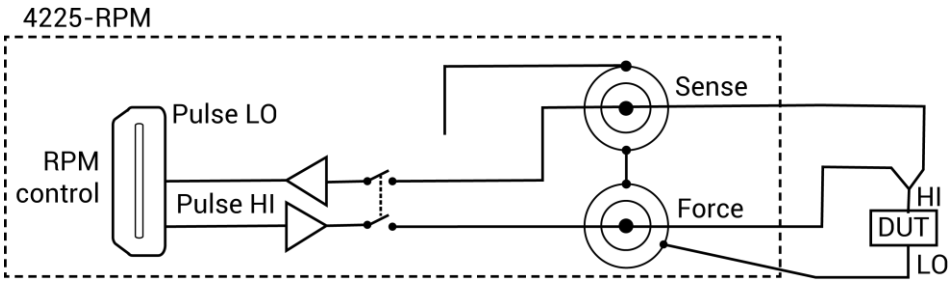
When mounting the 4225-RPM, make sure that there is a minimum of 5 cm (2 in.) of space between multiple RPM base assemblies. Spacing multiple 4225-RPM or 4200-PA instruments closer than 5 cm (2 in.) from the 4200-MAG-BASE can cause the internal relays to malfunction.

RPM diagrams for local and remote sensing

The following figure shows the diagram for local sensing. The center conductor of the Force triaxial connector is connected to the high side of the device under test (DUT) while the outer shield is connected to DUT LO. The Sense connector is not used.

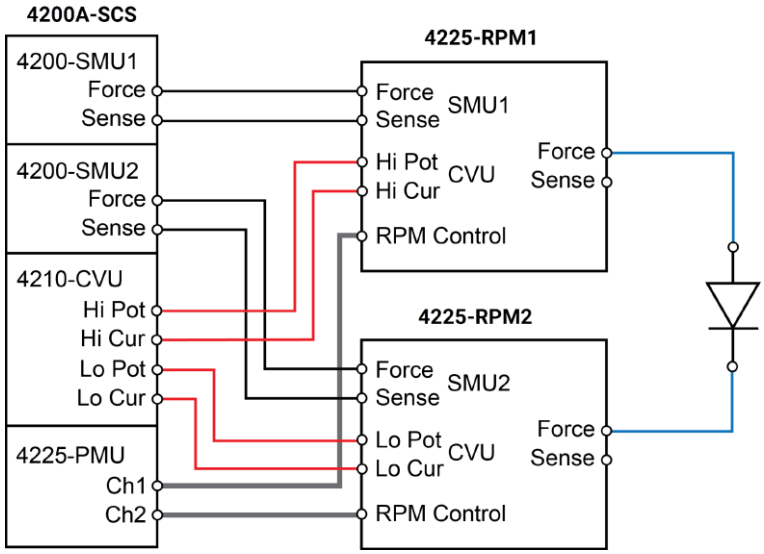


The following figure shows the diagram for remote sensing. Both Sense and Force are connected to DUT HI.



Using the RPM as a switch

You can use the RPM to switch a PMU, CVU, or SMU to a DUT terminal. The RPM wiring diagram (on page 7) figure shows the switches. The following figure shows a typical test configuration for using an RPM as a switch for a PMU, SMU, and CVU. In general, one RPM per device terminal is recommended. By default, the PMU (with RPM) is connected to the output unless a SMU or CVU is switched in.



Both the red cables (supplied with the CVU) and the blue cables (supplied with the optional 4210-MMPC cable kits) are 100 Ω. You can do remote sensing (on page 18) using the optional 4210-MMPC cable kits with the RPMs.

Control RPM switching

Before using an RPM, configure the 4200A-SCS by doing the steps in “Update the RPM configuration” in *Model 4200A-SCS Setup and Maintenance*. This properly associates the instruments connected to each RPM.

There are two methods to control RPM switching:

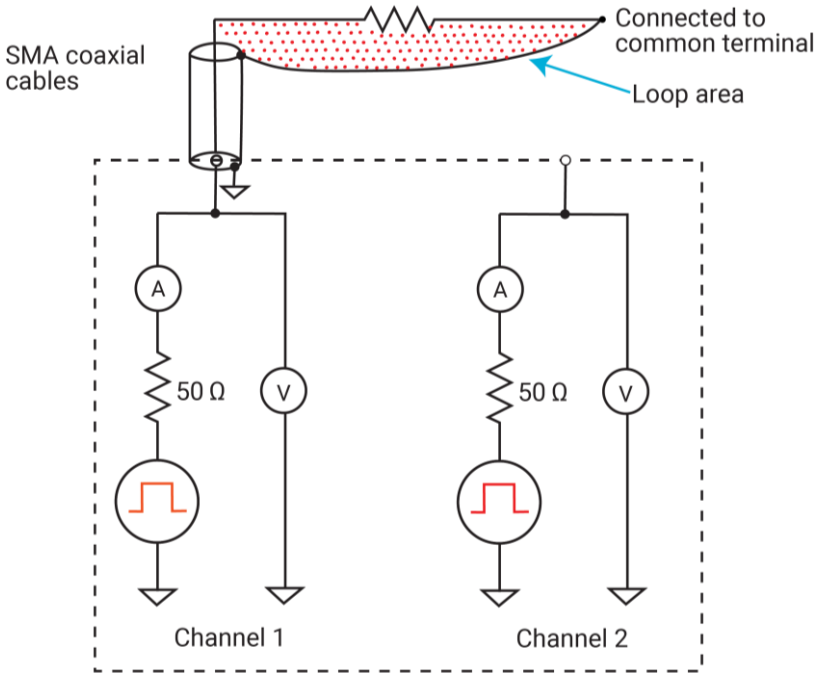
- ITM operation using automatic switching (after doing the steps in “Update the RPM configuration”)
- UTM testing from within the user module, use the LPT function `rpm_config`

CAUTION

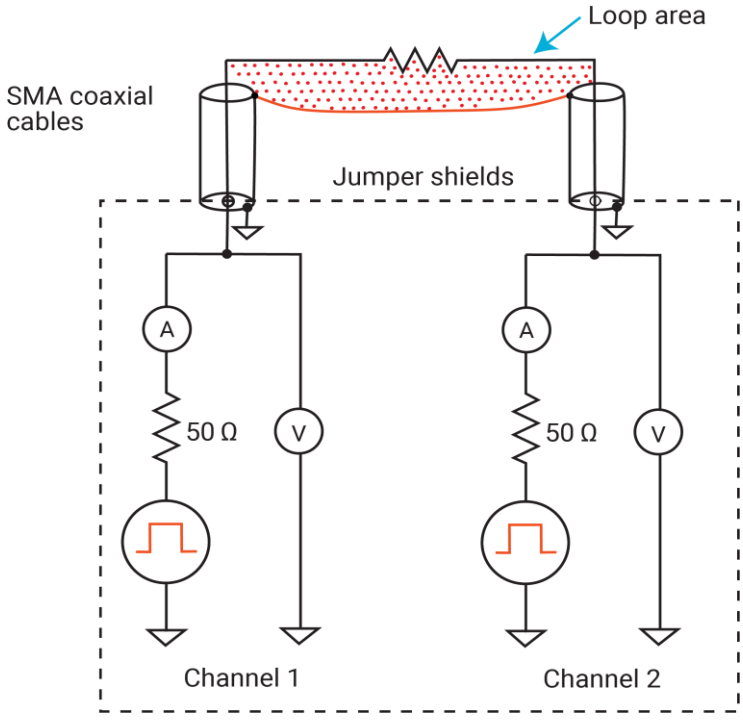
You must update the RPM configuration in KCon before using the RPM to control switching. If you do not, corrupt test data may result due to incorrect switch settings in the RPM.

Two-terminal device connections

The following figure shows connections to a two-terminal device using a single channel. Connect one end of the device to the center conductor of Ch 1 and connect the other side to pulse card common (outside shield of the SMA cable).

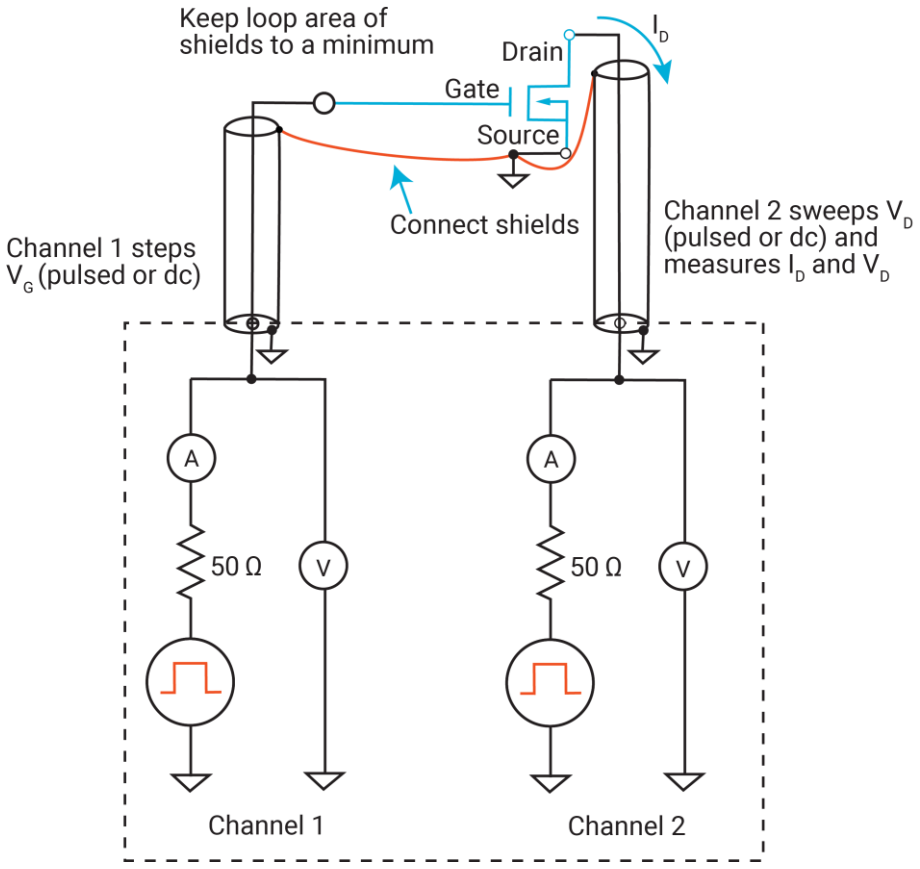


You can also connect a two-terminal device to the two channels of a PMU, as shown in the following figure. In this case, channel 1 will source/pulse voltage, and channel 2 will measure the resulting current. Make sure you connect the shields of the SMA cables close to the device under test. This method avoids problems of capacitive charging (see PMU capacitive charging/discharging effects (on page 64)).



Three-terminal device connections

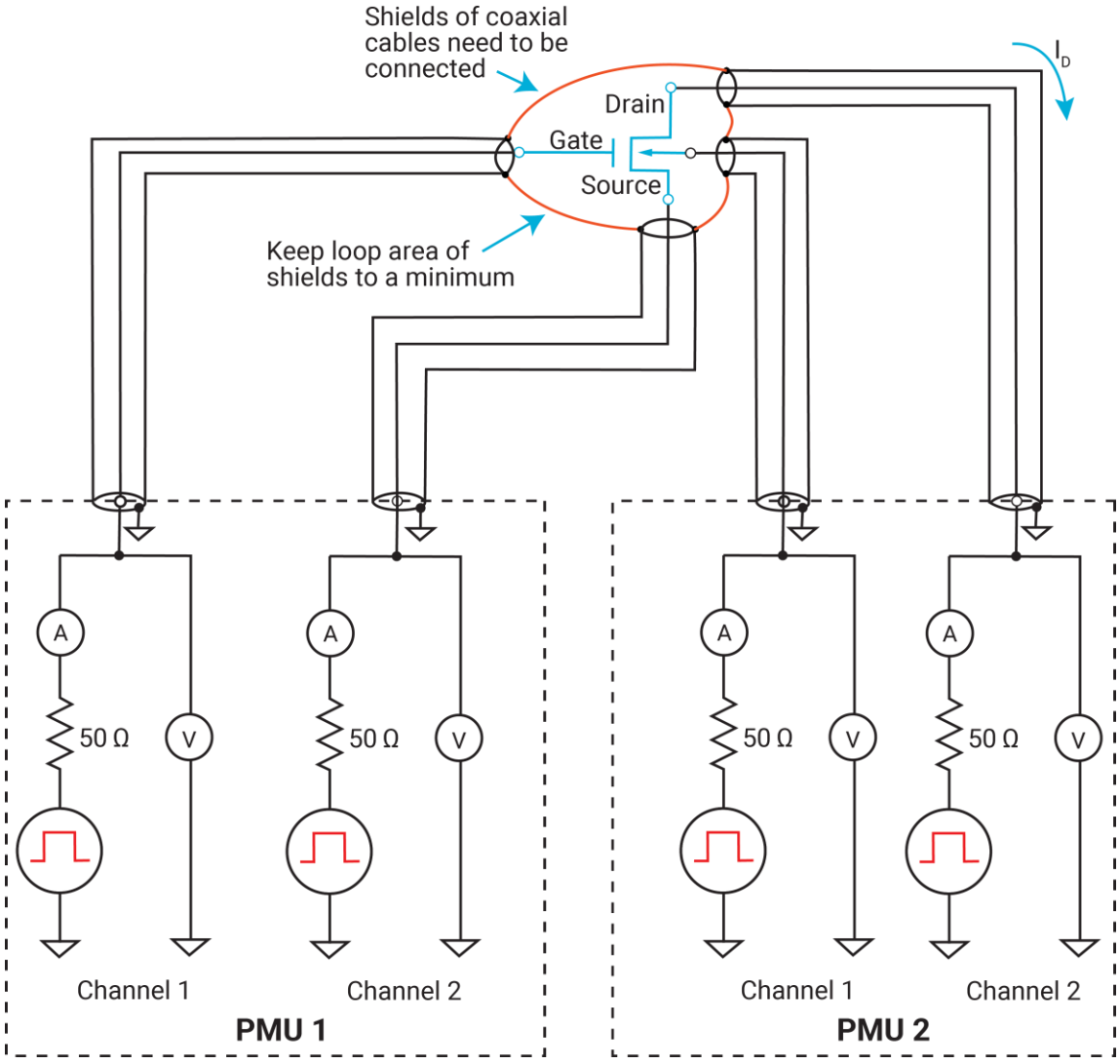
A three-terminal device can be connected using either two or three PMU channels, depending on if source and/or measure must be performed at each device pin. An example of both channels of a single PMU connected to a three-terminal MOSFET is shown in the following figure. In this example, connect the gate terminal to channel 1 of the PMU and connect the drain terminal to channel 2. Connect the source terminal to the outside shield of channel 2.



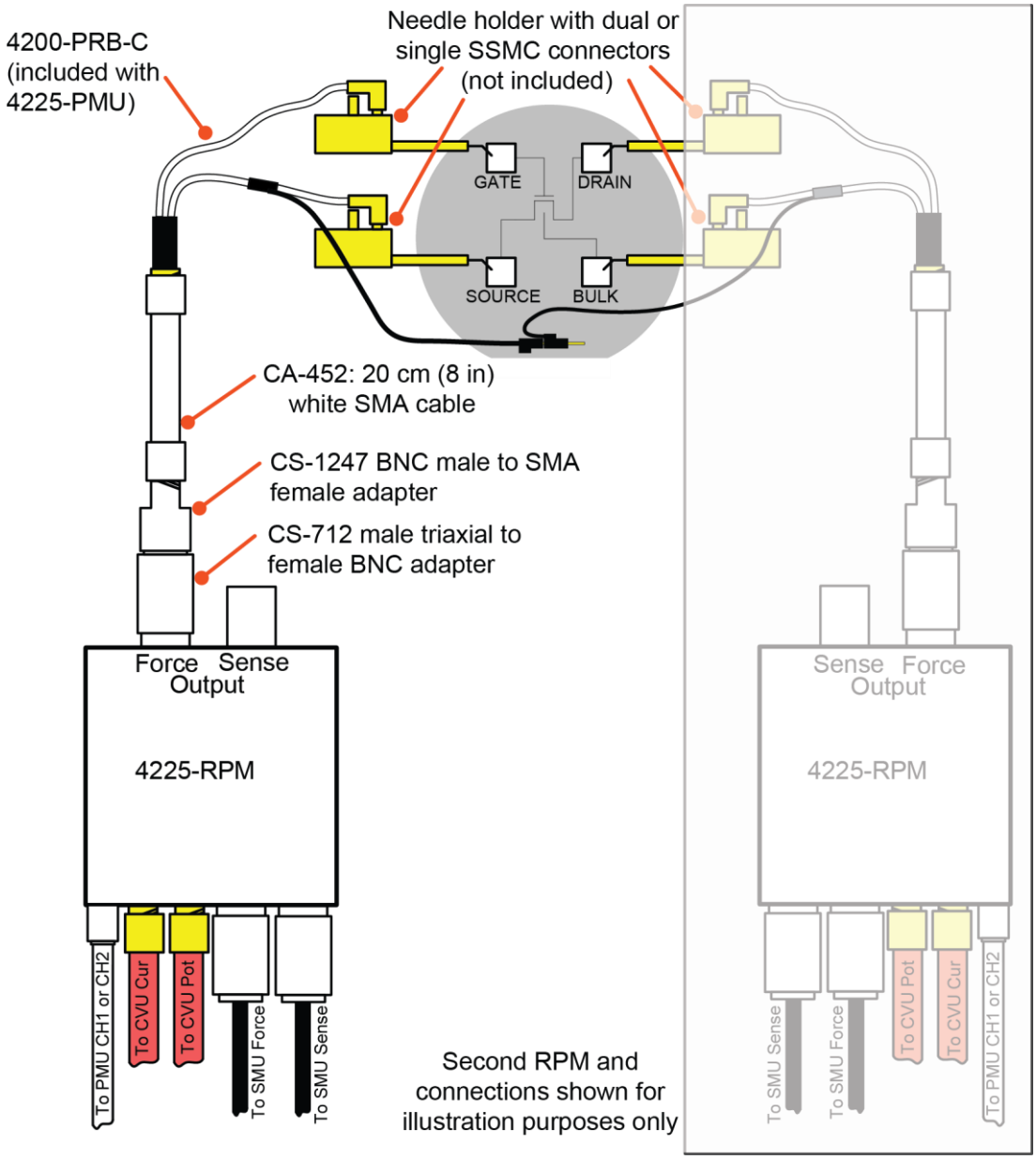
If ultra-fast I-V sourcing and measuring is required at each device terminal, then a second PMU is required for the source terminal. Up to four PMUs (eight channels) can be installed in one 4200A-SCS mainframe.

Four-terminal device connections

To test a four-terminal device, two PMUs are usually required. The following figure shows the four PMU channels connected to a four-terminal MOSFET. This configuration enables you to have complete flexibility to enable pulsing and measuring at any terminal on the device. Notice that the shields of the SMA cables from all four channels are connected as closely as possible to the device under test.



The following illustrates the connection to a 4-terminal device using the cabling and adapters that are included with either RPM or the 4225-PMU.



Pulse source-measure connections

NOTE

TRIGGER OUT of a pulse generator card can be connected to TRIGGER IN of other pulse generator cards to synchronize the start of pulse outputs. For details on using the trigger connectors, refer to Triggering (on page 97).

The cables used for SMU connections are supplied with the SMUs and preamplifiers.

NOTE

To achieve optimum performance, only use the cables, connectors, and adapters that are included with Keithley pulse source or measure kits.

⚠ WARNING

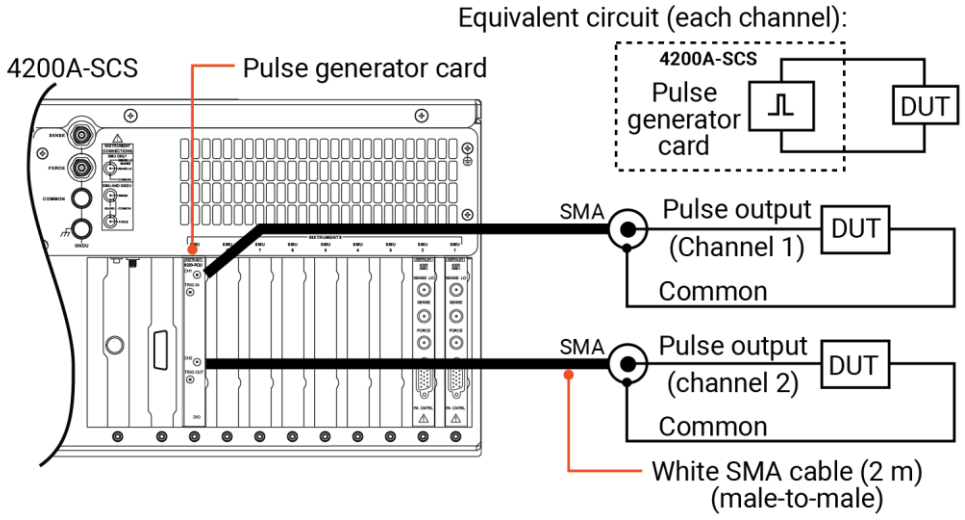
For the pulse source-measure configurations, ensure the 4200A-SCS high voltage is disabled. This will prevent a safety hazard that could result in possible injury or death because of SMU voltages greater than 42 V being applied to the device under test or fixture.

Pulse generator connections

The following figure shows a system that uses basic 2-channel pulse generator connections to DUTs.

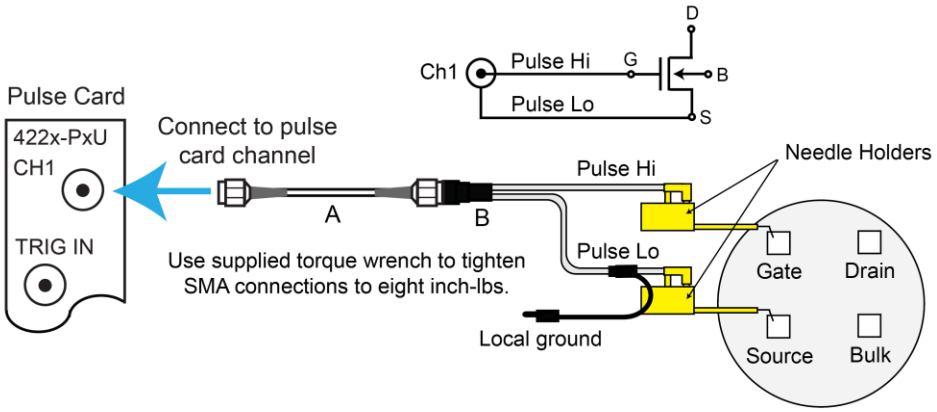
NOTE

Use the torque wrench supplied with the 4200A-SCS to tighten the SMA connections to 8 in. lb.



Using an adapter cable to connect pulse card to DUT

The following figure shows an example of how to make pulse card connections to the device under test (DUT) using the supplied SMA to SSMC adapter cable.



A	White SMA cable (2 m (6.5 ft), included with the PGU and PMU)
B	SMA to SSMC Adapter Cable (4200-PRB-C or CA-426D, included with the PGU and PMU)

The needle holders shown in the previous figure are supplied by the user.

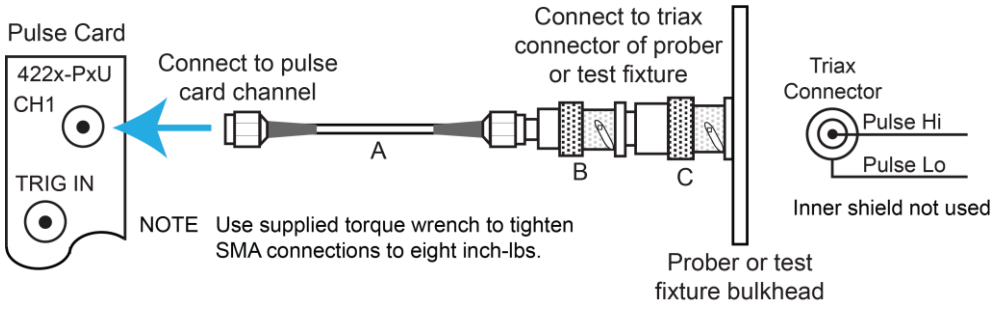
Connections to prober or test fixture bulkhead connectors

The 4200-PMU-PROBER-KIT (available from Keithley) is a collection of standard and custom connectors and accessories used to connect the pulse generator to a common variety of probe stations. This kit can also be used for pulse card connections to a test fixture.

The following figure shows an example of how a PMU or PGU can be connected to a triaxial connector of a prober or test fixture.

NOTE

If connecting to a prober or test fixture that uses BNC connectors, adapter C is not used.



A	White SMA cable (2 m (6.5 ft) included with the PGU or PMU)
B	SMA socket to BNC plug (included with the 4200-PMU-Prober-Kit)
C	BNC socket to three-lug triaxial plug (included with the 4200-PMU-Prober-Kit)

RPM connections to DUT

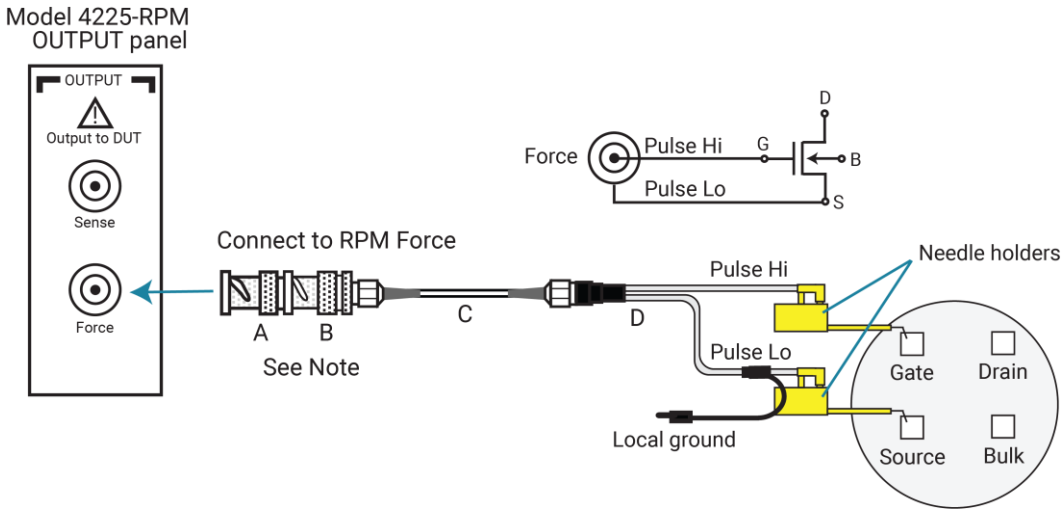
CAUTION

With an RPM installed, never make connections directly to any of the SMA connectors (CH1 and CH2) on the PMU module. This may result in damage to the PMU or DUT or may produce corrupt data.

A device under test (DUT) can be tested using local sensing or remote sensing. Local sensing is performed at the RPM, while remote sensing is performed at the DUT. When using remote sensing, errors due to voltage drops in the Force path between the RPM and the DUT are eliminated. With proper cabling, SMU or CVU tests provide remote sensing through the RPM.

Two-terminal test connections

For local sensing, only the Force output terminal of the RPM is connected to the DUT. The Sense output terminal is not used. The following figure shows local sense connections using the supplied adapter cable and adapters. For the two-terminal test shown in the following figure, the local ground is left unconnected. Test circuit low is connected to the shield of the Force connector through the cables.



NOTE

This connection method eliminates the triaxial guard (inner shield).

A	Triaxial plug to BNC socket adapter (supplied with the RPM)
B	BNC plug to SMA socket adapter (supplied with the RPM)
C	White SMA cable, 20.32 cm (8 in.) (supplied with the RPM)
D	SMA to SSMC adapter cable (4200-PRB-C or CA-426D, supplied with the PMU)

The needle holders shown in the previous two figures are supplied by the user.

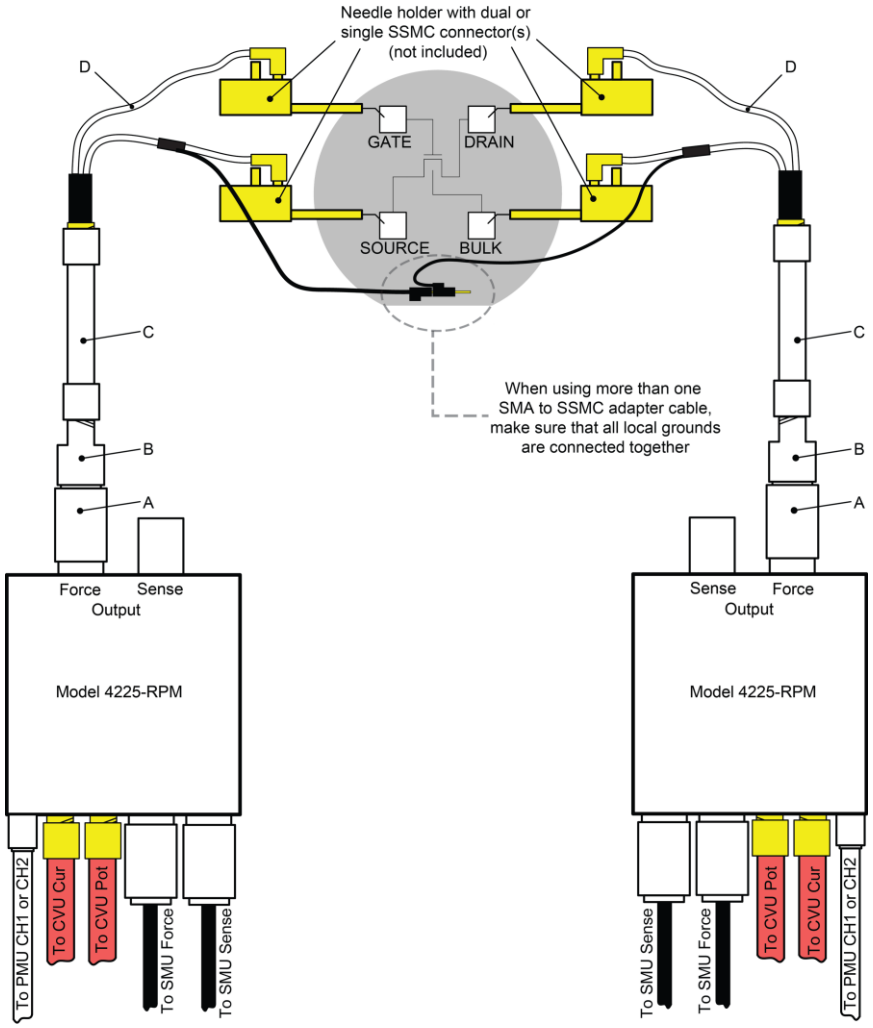
NOTE

When using two RPMs for four-terminal testing, two Y-cable assemblies are required. Make sure to connect the two local grounds of the two cable assemblies together (see the figure in RPM connections to a prober (on page 18)).

Remote sensing using RPM connections to a prober

Optional prober cable kits are available from Keithley. These kits provide connections to a DUT:

- Model 4210-MMPC-S: Use this cable kit with the Suss Micro Tec PA200/300 series prober.
- Model 4210-MMPC-C: Use this cable kit with the Cascade Microtech 12000 series prober (manipulator type DCM-200 series).
- Model 4210-MMPC-L: Use this cable kit with a Lucas Signatone Wavelink series prober.
- Model 4210-MMPC-W: Use this cable kit with the Wentworth prober.



A	Triaxial plug-to-BNC socket adapter (supplied with the RPM)
B	BNC plug-to-SMA socket adapter (supplied with the RPM)
C	White SMA cable (20.32 cm (8 in.), supplied with the RPM)
D	SMA-to-SSMC Adapter Cable (4200-PRB-C or CA-426D, supplied with the PMU)

NOTE

For details on using these prober cable kits, refer to PA-1000 for the Suss prober, PA-1001 for the Cascade prober, PA-1080 for the Lucas Signatone prober, and PA-1085 for the Wentworth prober.

PMU connection compensation

You can correct errors caused by connections and cable length between the 4225-PMU and the device under test (DUT) by using connection compensation. When connection compensation is enabled, the default or measured compensation values are factored into each DUT measurement.

Connection compensation includes short and offset current compensation options.

You have the option to use either default connection compensation values (PMU or RPM) or custom connection compensation values. The default values can be used for typical connection setups that use the supplied cables. The custom connection compensated values are generated when connection compensation is done from the Clarius software. The custom values provide optimum compensation. Custom connection compensation data is generated for offset current and short conditions. The custom connection compensation values can be enabled or disabled from a test in Clarius.

If connection compensation is disabled, the compensation values will not be applied to the measurements.

NOTE

For optimum performance, you should do connection compensation any time the connection setup is changed or disturbed. Changes in temperature or humidity do not affect connection compensation.

Short compensation

NOTE

For UTMs, the default connection compensation values for short can only be enabled using the LPT function `pulse_conncomp`.

You can perform short compensation to remove measurement errors due to stray resistance in your test configuration. When you run short connection compensation, the following status messages are generated:

- `Starting PMU Cable Compensation...`
- `R = % Ohms`
- `PMU Cable Compensation complete.`
- `% = value (V and I measured, Ohms calculated).`

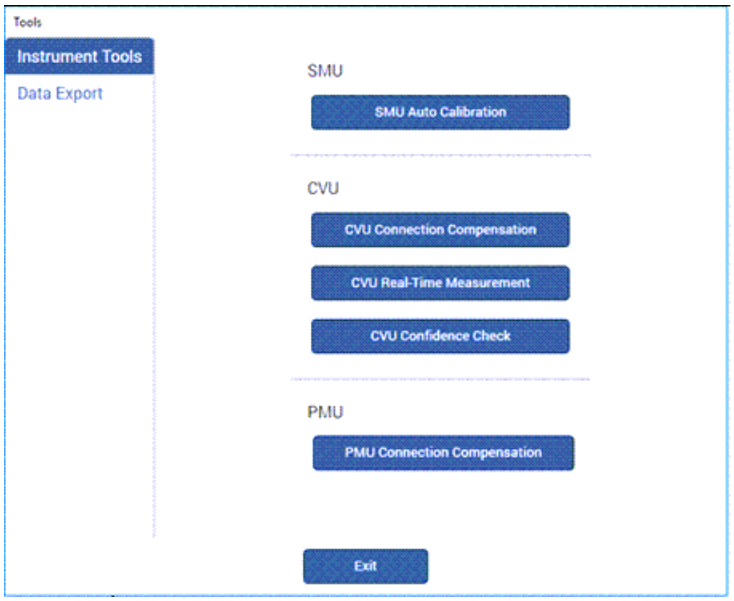
Offset current compensation

Error currents can be introduced into your pulsed measurements setup by PMUs. PMU offset compensation reduces error currents by subtracting measurements taken at 0 V from all subsequent readings.

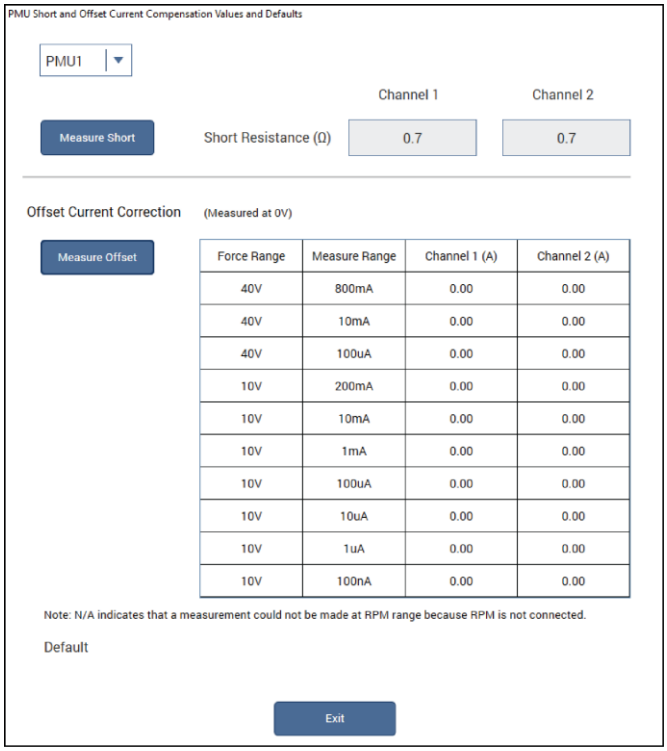
Perform connection compensation

To compensate for connections:

1. In Clarius, select **Tools**. The Clarius Tools dialog opens.



2. Select **PMU Connection Compensation**. The Short and Offset Current Connection Compensation Values and Defaults dialog opens.
3. From the PMU list, select the PMU that you want to perform compensation for.



4. To perform short connection compensation, select **Measure Short,** then follow the on-screen instructions or replace the DUT in the test fixture with a short.
5. To perform offset current compensation, select **Measure Offset**, then follow the on-screen instructions.

Compensation results are displayed when compensation is complete. If an error occurred, it is displayed in the Clarius Messages area. The compensation data is displayed in the Short and Offset Current Connection Compensation Values and Defaults dialog.

If your test setup uses both PMU channels, you will have new custom data for both channels.

Enabling connection compensation

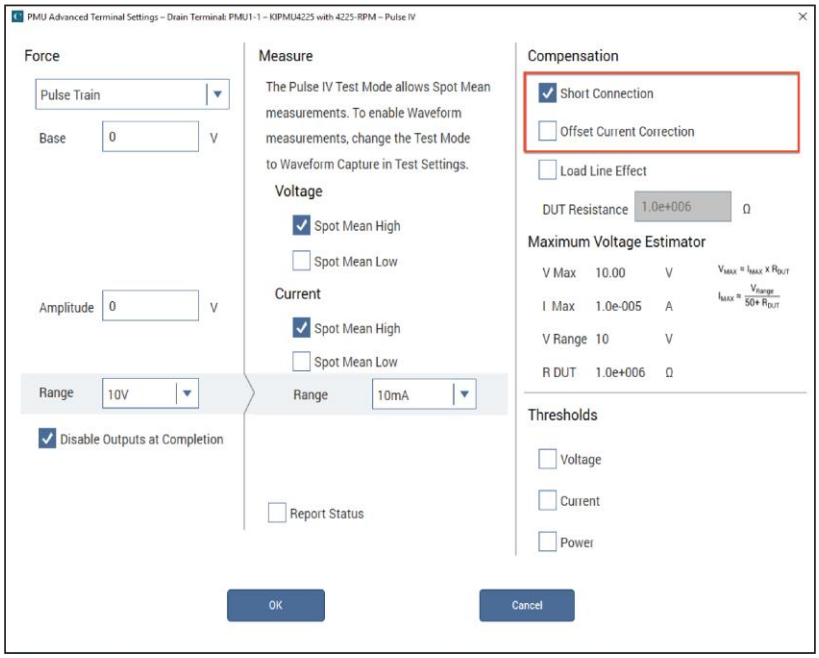
NOTE

This procedure is for ITMs. For UTMs, you need to enable connection compensation data using the LPT command `pulse_conncomp` or `setmode` functions.

To apply the connection compensation data to DUT measurements, you must enable connection compensation for the test.

To enable connection compensation:

1. Select the test.
2. Select **Configure**.
3. Select the terminal to be compensated.
4. In the right pane, select **Terminal Settings**.
5. Select **Advanced**. The PMU Advanced Terminal Settings dialog is displayed.
6. Select either **Short Connection** or **Offset Current Correction**.



7. Select **OK**.
8. To disable connection compensation, clear either **Short Connection** or **Offset Current Correction**, then select **OK**. When disabled, connection compensation values are not applied to DUT measurements.

Load-line effect compensation (LLEC) for the PMU

NOTE

Load-line effect compensation (LLEC) is only performed for standard pulse I-V testing using PMU measure ranges. It is not performed when using 4225-RPM measure ranges (≤10 µA). The active RPM circuitry provides its own analog LLEC (assuming there is a short cable from the RPM to the DUT).

The basic pulse output system is a series circuit that consists of the pulse generator resistance (fixed at 50 Ω), interconnect (cabling and pin-to-pad) resistance, and the resistance of the DUT. In this series circuit, the sum of the voltage drops across these components is equal to the output voltage of the pulse generator. Therefore, if the resistance of the DUT changes, the voltage seen at the DUT also changes. This effect is called the load-line effect. See DUT resistance determines pulse voltage across DUT (on page 92) for details on how the resistance of the DUT affects the voltage across it.

For example, consider a PMU set to output voltage to a 50 Ω load (DUT). For this default setting, the pulse card outputs twice the programmed pulse voltage. If the interconnect resistance is negligible (0 Ω), half the pulse card voltage appears across the internal pulse card resistance (50 Ω) and the other half (which is the programmed pulse voltage) appears across the 50 Ω DUT. For example, if the pulse card is programmed to output a 5 V pulse, the pulse card sources a 10 V pulse. Five volts will drop across the internal 50 Ω pulse card resistance and 5 V will appear at the 50 Ω DUT.

The 4225-RPM also exhibits the load-line effect. The RPM has resistance in series with its output (typically between 20 Ω and 50 Ω).

NOTE

Descriptions of the LPT functions discussed in the following topics are provided in *Model 4200A-SCS LPT Library Programming*.

Methods to compensate for load-line effect

The methods to compensate for load-line effect include:

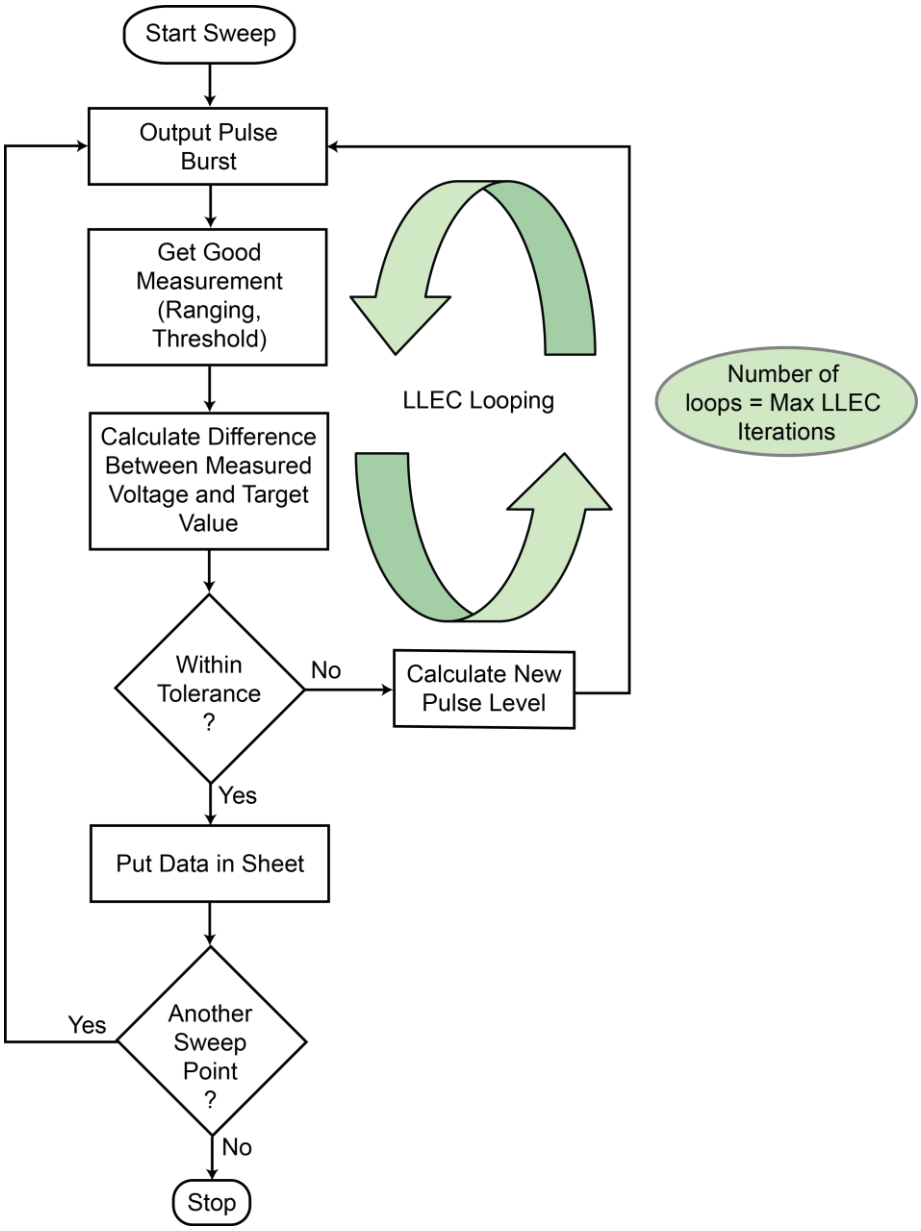
- Use the built-in load-line effect compensation (LLEC) in the PMU for the standard 2-level pulse mode. Ideally (when LLEC is enabled), the PMU adjusts its output levels such that the programmed output voltage appears at the DUT. For ITMs, see Load-line effect compensation (on page 23). For UTMs, use the LPT `pulse_meas_sm` function to control LLEC.
- Manual adjustment of the PMU output until the target pulse level is measured across the DUT. For a pulse sweep, this manual process must be repeated for every step in the sweep.

If you are not using LLEC, you can manually set the output impedance to match the impedance of the DUT. For example, if the impedance of the DUT is 1 kΩ, set the output impedance to 1 kΩ. Maximum power transfer is achieved when the DUT impedance matches the output impedance setting. In a real test environment, you may not know the exact resistance value of the DUT, and you will have the added affect of cabling and pin-to-pad resistance. The output impedance can be set from an ITM (see Disable LLEC and set the output impedance (on page 31)) or from a UTM (see the LPT `pulse_load` function).

How LLEC adjusts pulse output to the target levels

LLEC is an algorithm that adjusts the output of a PMU channel. When enabled, the algorithm performs a set number of iterations in an attempt to output the target voltage to the DUT.

The algorithm used for LLEC is shown in the following figure. The diagram shows that the PMU standard pulse source (with measure) uses a burst-measure-analyze-reburst method. This method allows for range changing, threshold comparison, load-line effect compensation, and pulse timing. This means there is separation between each set, or burst, of pulses. The number of pulses output for each attempt is controlled by the Number of Pulses setting for ITMs or the `pulse_meas_timing` function for UTMs. Note that LLEC is available only in the standard 2-level pulse mode. LLEC is not available in the Segment Arb mode.



Note that after the first action, "Output Pulse Burst," all pulse channels in the test stop pulsing and output 0 V while performing the actions in the remaining boxes in the diagram. The time between pulses is determined by the time required to process the measurements and perform the calculations and comparisons shown in the previous figure. Wider pulses, longer pulse periods, and a higher number of pulses increases the time between pulses where the output is at 0 V. Note that both Pulse I-V and Waveform Capture Test modes use this algorithm and both will output 0 V between pulses for each step in a sweep. For strict control over the pulse voltage versus time, see the Segment Arb feature of the PMU.

The "Get Good Measurement" step shown in the previous figure also must ensure that the current measure range is correct (if ranging is enabled) and check the measured voltage and current against the thresholds. See PMU - all terminal parameters (on page 37).

There are two parameters that control how the LLEC algorithm functions: Maximum number of iterations and tolerance window. For ITMs, the maximum number of iterations is fixed at 20 and the tolerance window is 0.3 percent. For UTMs, use the `setmode` function. The LLEC algorithm iterates, trying to reach the target voltage until one of the following occurs:

- The target voltage is reached (within tolerance specified).
- The maximum number of iterations is reached. The maximum number of iterations must be equal for each channel in the test.

Coping with the loadline effect

There are several ways of working with this effect. The simplest one is to program the DUT load into the pulse card channel using the `pulse_load` function, or setting the Pulse Load value in the KPulse (on page 108) virtual front panel. The pulse card calculates the appropriate V_{INT} to output so that the V_{DUT} pulse waveform, specified by `pulse_vlow` and `pulse_vhigh`, has the correct levels. This works well for high impedance devices or device terminals (R_{DUT} = 1 kΩ), such as the gate terminal on a CMOS field effect transistor (FET). Unfortunately, many times R_{DUT} is not known or varies. A key example of a varying R_{DUT} is the drain-source resistance during a V_D-I_D sweep, where R_{DS} is changing from point-to-point and sweep-to-sweep.

There is basically only one way to handle this situation, with two different levels of implementation. In general, assume the DUT is a FET. If the test consists of a single or limited number of gate and drain test points, the necessary voltages can be determined by pre-characterizing each unique set of test conditions.

This pre-characterization requires some way to measure the pulse heights, which is typically done using an oscilloscope and an iterative trial and error approach. Each test voltage needs to be measured, with the pulse levels adjusted until the correct voltage is reached. Record each pulse level required to reach the required V_{DUT} levels.

For information on the LPT commands listed above, refer to *Model 4200A-SCS LPT Library Programming*.

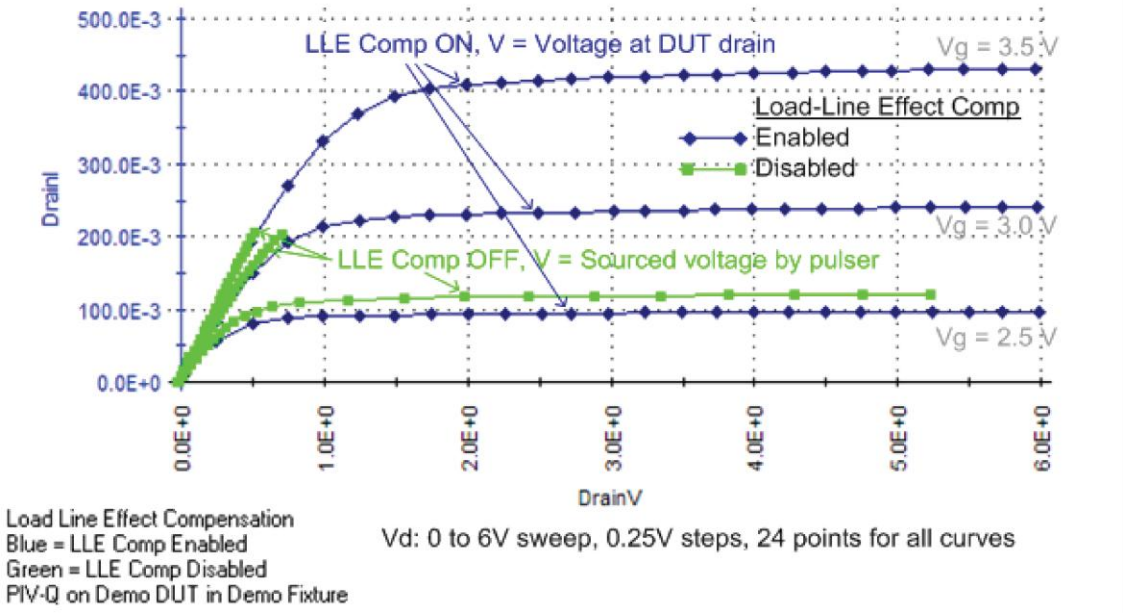
NOTE

The 4225-PMU has built-in load-line effect compensation. For details, see Load-line effect compensation (LLEC) for the PMU (on page 23).

LLEC maintains even voltage spacing

Another advantage of using LLEC is that it maintains even voltage spacing during the test. For example, if the pulse sweep uses 250 mV steps, DUT voltage and current measurements are made at every 250 mV step. Data that is generated using even voltage spacing is ready to be fed into a mathematical model.

When not using LLEC, uneven voltage spacing may result due to load-line effect. The following figure shows load-line effect on a FET family of curves. The blue curves were generated with LLEC enabled and the green curves were generated with LLEC disabled. The Vg was increased for the green curves to provide separation between the curves.



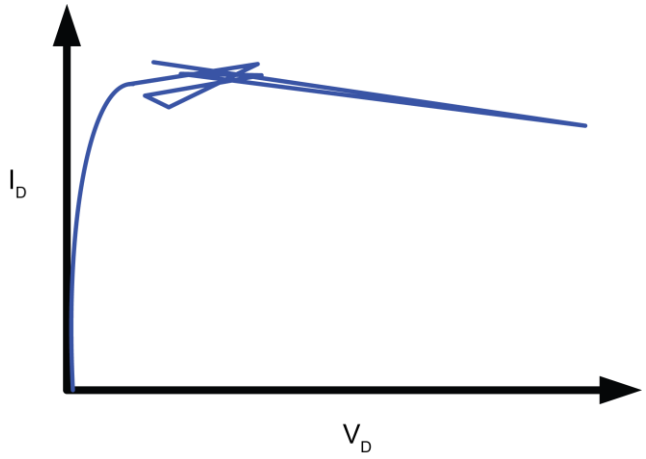
In the previous figure, each blue curve (LLEC on) is the result of a sweep from 0 to 6 V using 250 mV steps. Notice that the 24 pulse-measure points are evenly spaced.

The same sweep is used to generate the green curves (LLEC off). The best green curve is the one at the bottom (bias V_g = 2.5 V). However, load-line effect prevents the PMU from sourcing 6 V to the DUT and the 24 pulse-measure points are not evenly spaced. Modifying the sweep to 0 to 6.5 V will ensure that at least 6 V is output to the DUT, but voltage spacing will still be uneven. The green curves for the other two bias voltages (V_g = 3.0 V and 3.5 V) are even more adversely affected by load-line effect.

Test considerations

The magnitude of the pulse steps affects overall test time. Wider pulses, a higher number of pulses, and larger voltage steps at each sweep point, all increase the amount of time required for the LLEC algorithm at each sweep point, which lengthens the overall test time.

There may be some high-gain devices that will not test properly with LLEC enabled. In this case, you can disable LLEC. To disable LLEC in ITMs, see Disable LLEC and set the output impedance (on page 31). For UTMs, see the `pulse_meas_sm` and `pulse_meas_wfm` functions.



LPT functions used to configure LLEC

The LPT functions used to configure LLEC for the PMU are:

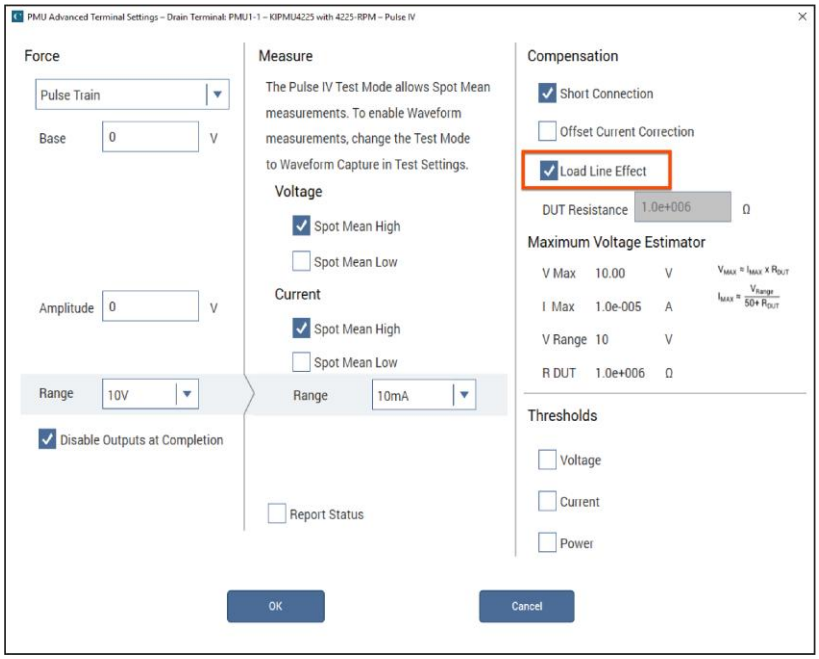
- `pulse_load`: Use this function to set the output impedance for the DUT when LLEC is disabled. Setting the DUT resistance is useful when the DUT resistance is known and is relatively constant
- `setmode`: Use this function to set the number of iterations for the LLEC algorithm or the tolerance window that determines if load-line effect compensation is reached. The tolerance window is expressed as a percentage of the target voltage. The maximum number of iterations sets the maximum number of iterations that will be attempted by the LLEC algorithm. If the algorithm does not reach the target window, the measurements from last attempt are returned.
- `pulse_meas_sm` and `pulse_meas_wfm`: Use these functions to enable or disable LLEC.

Enable LLEC

This option is available for ITMs.

To enable LLEC:

1. Select the pulse test.
2. Select **Configure**.
3. In the right pane, select **Terminal Settings**.
4. Select **Advanced**.
5. Select **Load Line Effect**, as shown in the following figure.
6. Select **OK**.



Disable LLEC and set the output impedance

These options are available for ITMs.

With LLEC disabled, you can input the known resistance of the DUT. The resistance value is then used in a compensation process to output the voltage.

The Max Voltage Estimator is a tool that you can use to calculate the maximum voltage and current based on the selected voltage range and the entered DUT resistance value. The estimator does not affect the pulse output.

For a more accurate maximum voltage estimate, add the interconnect resistance to the DUT resistance value. The typical resistance of a white SMA cable is 0.75 Ω and the typical prober pin-to-pad resistance is 1 Ω to 3 Ω. Poorer pin-to-pad contacts could be in the range from 10 Ω to 15 Ω.

The LLEC setting does not change the maximum output voltage or current of the PMU. The V Max and I Max values are the maximum output of the PMU and are valid if LLEC is enabled or disabled. The DUT Resistance setting also does not affect the maximum output voltage. For example, the 10 V range can output 10 V into a high-impedance DUT (1 MΩ) and a lower voltage into lower impedance DUTs. Refer to DUT resistance determines pulse voltage across DUT (on page 92) for details on calculating DUT resistance.

To disable LLEC and set the output impedance:

1. To disable LLEC, clear **Load Line Effect**.
2. In the DUT Resistance box, enter the resistance value.
3. Review the Max Voltage Estimator values.
4. Select **OK**.

Section 3

Setting up PMUs and PGUs in Clarius

Introduction

This section provides basic information on creating a PMU project in Clarius and specific information on the options available for PMUs and PGUs.

For additional detail on working with Clarius, refer to the *Model 4200A-SCS Clarius User Manual*.

Configure the PGU, PMU, and RPM using tests

To configure and control the PGU, a user test module (UTM) is needed. You can also use UTMs to configure and control the PMU and RPM preamplifier. For UTM programming, see “LPT commands for PGUs and PMUs” in *Model 4200A-SCS LPT Library Programming*.

You can use interactive test modules (ITMs) to configure and control a PMU and RPM preamplifier. Refer to “Configure a simple test” in *Model 4200A-SCS Clarius User Manual* for information on configuring an ITM for the PMU.

An ITM automatically controls the RPM based on the type of test (pulse, CV, SMU). RPM switching can only be controlled using the `rpm_config` LPT function in a UTM. For details, refer to Using the RPM as a switch (on page 9).

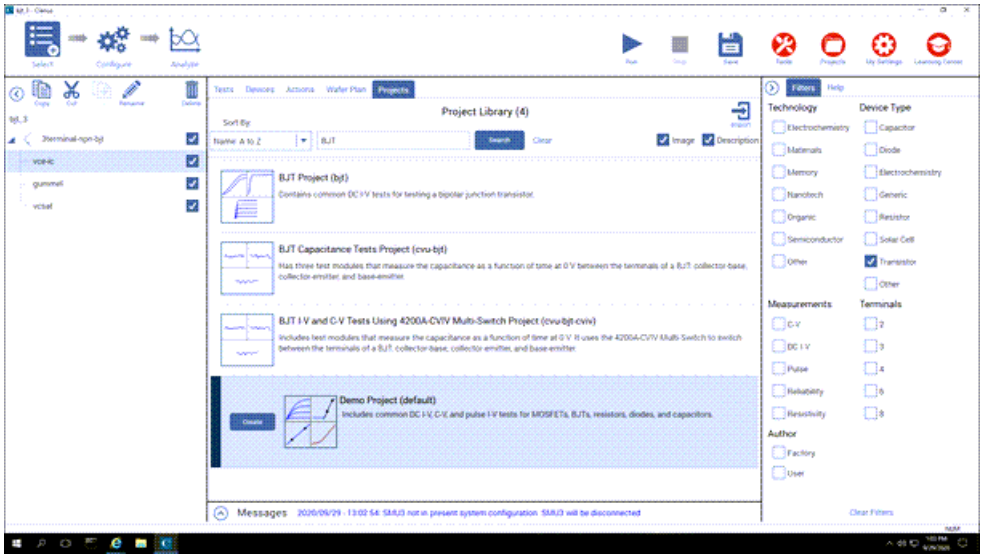
NOTE

For automatic switching of the RPM in ITMs, the RPM must already have all instrument cabling connected and recognized by the system. Information on performing this update is in “Update the RPM configuration” in *Model 4200A-SCS Setup and Maintenance*.

Create a PMU project

To create a new project:

1. Select **Save** to save your existing project.
2. Choose **Select**.
3. Select the **Projects** tab.
4. In the Search box, type **PMU** and select **Search**. The Library displays projects that are set up for PMUs.
5. Select **Create** for the project you want to open. The project replaces the previous project in the project tree.



6. Assign a new title to the project by selecting **Rename** and then entering an appropriate name.
7. Select **Enter**.

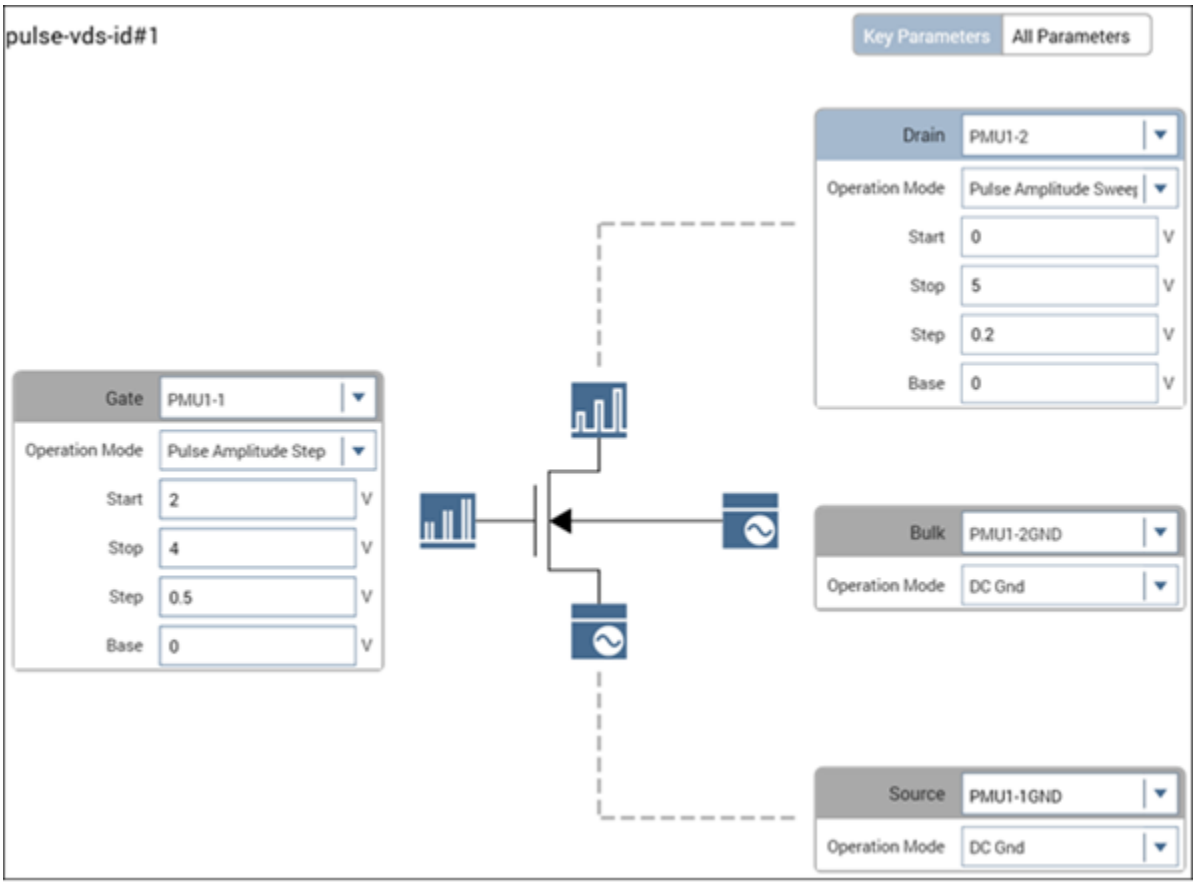
Configure the tests

To configure a test:

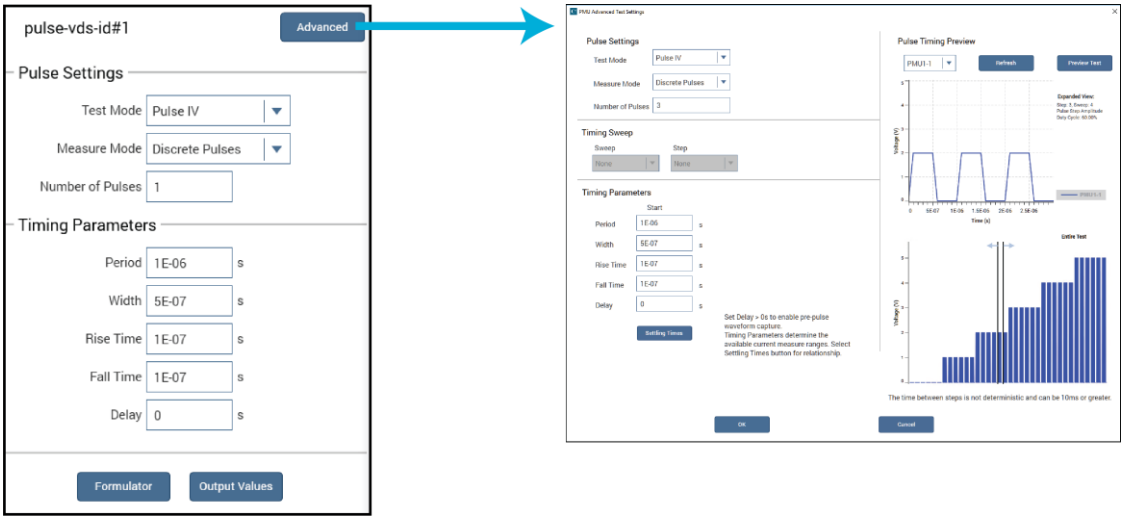
1. Select **Configure**.



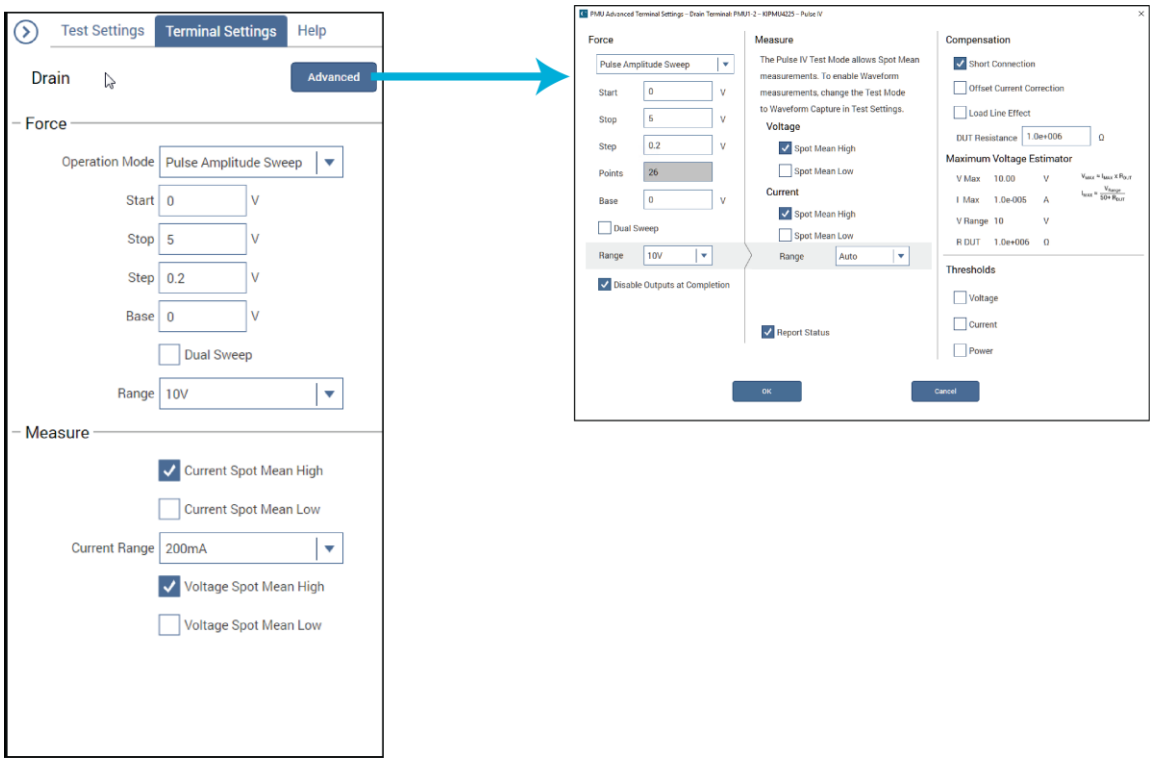
2. From the Key Parameters pane, adjust the pulse voltage sweep levels of PMU1-2 on the Drain terminal and the Pulse Step Voltage of PMU1-1 on the Gate terminal, as needed.



3. From the Test Settings pane and Advanced Test Settings dialog, adjust the Pulse Settings and Timing Parameters as needed.

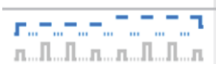


4. From the Terminal Settings pane and Advanced Terminal Settings dialog, you can adjust the voltage source and current measurement parameters, as needed.



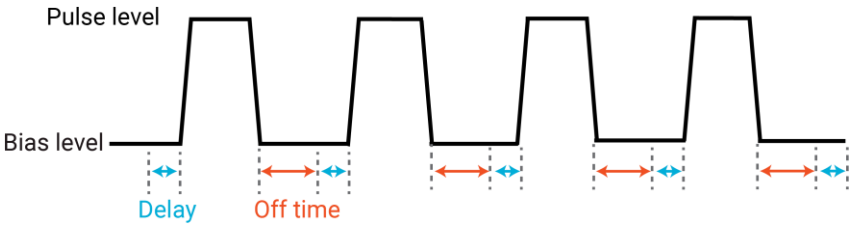
PMU operation modes

The operation mode determines what type of test is run on the terminal. Selecting the appropriate mode simplifies configuration options. The pulse operation modes are shown in the following figure.

Pulse sweep		Amplitude sweep
		Base sweep
		DC sweep
Pulse step		Amplitude step
		Base step
		DC step
Pulse train		Pulse train
		DC train
Pulse dual sweep		Amplitude sweep
		Base sweep
		DC sweep
Pulse dual sweep with step		Amplitude step
		Base step
		DC step

A Pulse Sweep and Pulse Step function are identical. However, in a test where two or more PMUs are used, the sweep for one PMU is performed on each step of the pulse step of the other PMU. A pulse step requires that at least one channel be configured for Pulse Sweep.

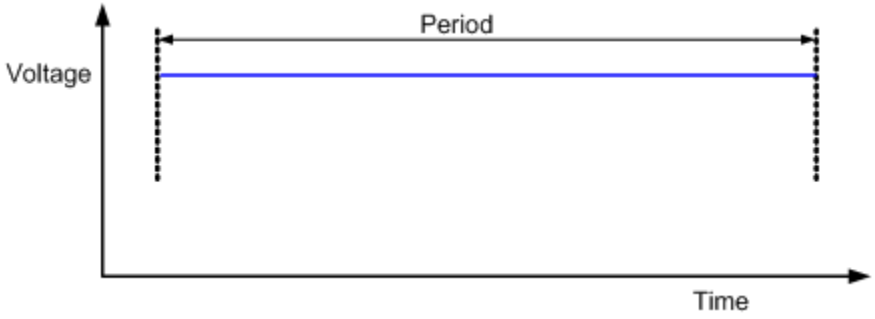
A Pulse Train outputs one or more pulses of the same magnitude and base level, as shown in the following figure.



The DC Gnd operation mode is used for the PMU GND terminal.

When there are two or more PMUs in the test system, the Sweep Master (on page 51) option is used to select one of them as the master PMU.

When DC Bias operation mode is selected, the PMU outputs the DC base voltage. The following figure shows a representation of a DC voltage waveform.



The terminal settings available for each operation mode are described in the following topics.

PMU – all terminal parameters

When you select **All Parameters**, the Configure pane displays all available parameters for the test that is selected in the project tree.

Parameter descriptions are provided in the following topics.

Start (PMU Amplitude Sweep)

The voltage source level at which the sweep starts.

Stop (PMU Amplitude Sweep)

The voltage source level at which the sweep stops.

Step (Pulse Amplitude Sweep)

The voltage size of each step of the sweep. The source level changes in equal steps of this size from the start level to the stop level. A measurement is made at each source step (including the start and stop levels).

Clarius never steps the force voltage beyond the value specified by the stop parameter, even if you specify a step value that is larger than the stop value.

Use a step value that does not result in a fractional number of points. If the point is fractional, the step value is forced to a value that results in a whole number of points. To calculate the points:

$$points = \frac{(stop - start)}{step} + 1$$

The points are rounded to the nearest value.

For example, if Start = 0 V, Stop = 5 V, and Step = 0.6 V:

$$points = \frac{(5 - 0)}{0.6} + 1$$

In this case, the Step value is forced to 0.625 V, which results in a point value of 9.333, which is rounded to 9. The instrument forces nine voltages at 0 V, 0.625 V, 1.25 V, 1.875 V, 2.5 V, 3.125 V, 3.75 V, 4.375 V, and 5 V.

Points

The number of points that are measured. This value is calculated by Clarius using the information entered for the Start, Stop, and Step parameters, using the following equation:

$$points = \frac{(stop - start)}{step} + 1$$

Base

The voltage offset (from 0 V) that is the reference for the pulse amplitude.

Amplitude

The amplitude voltage.

Dual Sweep (pulse)

When you enable Dual Sweep, the instrument sweeps from start to stop, then from stop to start. When you disable Dual Sweep, the instrument sweeps from start to stop only.

The amplitude, base, and DC sweeps have an option for Dual Sweep. The following figure shows the difference between a single pulse sweep and a dual pulse sweep. This following figure illustrates a linear voltage sweep that sweeps from 0 V to 4 V in 1 V steps.



Force Range (PMU)

The range that is used when sourcing. Select one of the listed ranges. The source remains on the range that is set. If you are sweeping and a sweep point exceeds the source range capability, the source outputs the maximum level for that range. This range must be equal to or greater than the largest value in the sweep.

Note that the 40 V range has a higher maximum output voltage and current, but does not have the faster transition times of the 10 V range or the lower current measure ranges of the 4225-RPM.

Disable outputs at completion

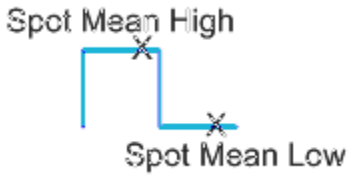
Select this option to disable the outputs when the test completes.

Clear this option to leave the outputs enabled when the test completes.

Current Spot Mean High

Makes current measurements on the amplitude. Available when the Test Mode is set to Pulse I-V.

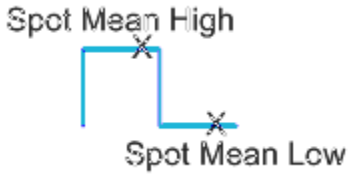
The following figure shows an example of a spot mean measurement on pulse high (amplitude) and pulse low (base level). For a more detailed example, refer to Test Mode (PMU) (on page 48).



Current Spot Mean Low

Makes current measurements on the base level. Available when the Test Mode is set to Pulse IV.

The following figure shows an example of a spot mean measurement on pulse high (amplitude) and pulse low (base level). For a more detailed example, refer to Test Mode (PMU) (on page 48).



Measure Current Range (PMU)

The measure range determines the full-scale measurement span that is applied to the signal. Therefore, it affects both the accuracy of the measurements and the maximum signal that can be measured.

The current measure range affects the time required to obtain settled measurements. Lower current ranges require additional time to reach a settled signal level. If the pulse timing parameters are too short for one or more current measure ranges, some ranges are unavailable.

As shown in the following table, available current measurement ranges for the PMU depend on the selected voltage source range. The 10 mA measure range for the 10 V source range has better accuracy than the 10 mA range for the 40 V source range.

Fixed current measurement ranges (PMU only)	
10 V range	**40 V range**
10 mA	100 µA
200 mA	10 mA
–	800 mA

If you are using an RPM, additional current measurement ranges become available to the PMU. The following table lists the current measurement ranges for the PMU when using the RPM. The 10 mA measure range for the 10 V source range has better accuracy than the 10 mA range for the 40 V source range.

Current measurement ranges for the PMU with RPM	
10 V range	**40 V range**
100 nA	100 µA
1 µA	10 mA
10 µA	800 mA
100 µA	—
1 mA	—
10 mA	—
200 mA	—

The current range options are:

- **Auto:** The instrument automatically optimizes the measurement range as the test progresses. This option provides the best resolution when the measurements span several decades. However, time delays can occur with range changes that can limit the measurement speed.
- **Limited Auto:** A compromise between Auto and a fixed range option. It allows you to specify the minimum range that the PMU uses when it automatically optimizes the current measurements. This option reduces test time when you do not need maximum resolution at minimum currents. The available ranges are limited by the chosen pulse timing parameters. For additional information, see PMU minimum settling times versus current measure range.
- **Specific ranges:** You can select a fixed measurement range.

The available ranges are limited by the pulse timing parameters. For additional information, see PMU minimum settling times versus current measure range (on page 56).

Low Range

Available when the Measure Range is set to Limited Auto. This sets the minimum range that the instrument uses.

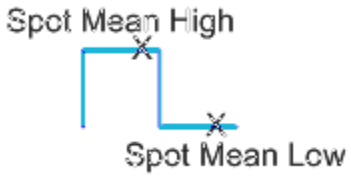
Current Sample Waveform

Makes current measurements on the waveform. Available when the Test Mode is set to Waveform Capture.

Voltage Spot Mean High

Makes voltage measurements on the amplitude. Available when the Test Mode is set to Pulse IV.

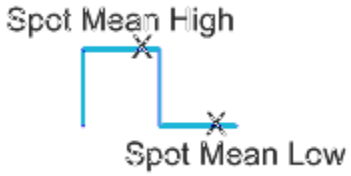
The following figure shows an example of a spot mean measurement on pulse high (amplitude) and pulse low (base level). For a more detailed example, refer to Test Mode (PMU) (on page 48).



Voltage Spot Mean Low

Makes voltage measurements on the base level. Available when the Test Mode is set to Pulse IV.

The following figure shows an example of a spot mean measurement on pulse high (amplitude) and pulse low (base level). For a more detailed example, refer to Test Mode (PMU) (on page 48).



Voltage Sample Waveform

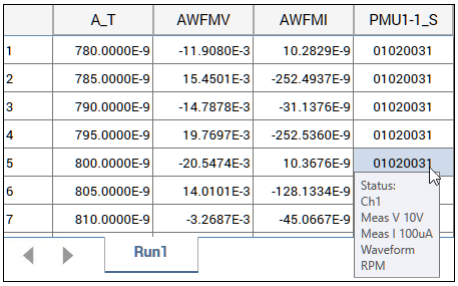
Makes voltage measurements on the waveform. Available when the Test Mode is set to Waveform Capture.

Report Timestamps

Available when the Test Mode is set to Waveform Capture. When Report Timestamps is enabled, each measurement includes a timestamp and the waveform is graphed (voltage/current versus time) in the Analyze graph.

Report Status (PMU)

When this option is selected, Clarius records measurement status information when the test executes. A column of the Analyze spreadsheet displays this information. Hover over a cell to review the information. An example of the status information is displayed in the following figure.



For PMU measurements, this information is also available as a 32-bit word. The status code bit map is listed in the LPT `pulse_fetch` command description.

PMU measurement status

ITMs can provide status information for the 4225-PMU measurements in the Analyze sheet Run tab. The column for the status codes is labeled PMU*x*_*y*_S, where *x* is the PMU instrument number (PMU1, PMU2, and so on), and *y* is channel number (channel 1 or 2). The PMU status code indicates pulse measurement status, source and measure ranges, whether an RPM is connected, and load-line effect compensation (LLEC) status, and flags any faults (errors).

If a pulse measurement fault occurs, the data values in the entire row are displayed in a different color. A single measurement may have more than one condition. Hover over a cell to review the status information.

The data values identify the fault type as follows:

- Red = Source in compliance
- Magenta = Measurement overflow
- Orange = LLEC failed
- Blue = Current, voltage, or power threshold reached

An example of the Analyze sheet when a measurement overflow occurred is shown in the following figure. The figure also shows an example of the message that is displayed when you place the cursor on a flagged `PMU1_1_S` cell.

	Drain_T	DrainWFMV	DrainWFMI	PMU1_2_S	Gate_T	GateWFMV	GateWFMI	PMU1_1_S
1	0.0000E+0	-90.0662E-3	213.3115E-6	01020042	0.0000E+0	-94.7004E-3	173.3478E-6	01020041
2	5.0000E-9	46.6457E-3	436.7055E-6	01020042	5.0000E-9	34.8143E-3	396.1551E-6	01020041
3	10.0000E-9	950.1271E-3	642.6028E-6	01020042	10.0000E-9	804.0382E-3	618.2225E-6	01020041
4	15.0000E-9	2.1097E+0	824.8849E-6	01020042	15.0000E-9	1.8658E+0	809.9987E-6	01020041
5	20.0000E-9	3.3532E+0	991.7982E-6	01020042	20.0000E-9	3.0139E+0	991.9069E-6	01020041
6	25.0000E-9	4.8719E+0	1.1244E-3	01020842	25.0000E-9	4.4979E+0	1.1193E-3	01020841
7	30.0000E-9	6.4245E+0	1.1242E-3	31020842	30.0000E-9	5.9473E+0	1.1192E-3	31020841
8	35.0000E-9	7.8830E+0	1.1241E-3	31020842	35.0000E-9	7.4889E+0	1.1190E-3	31020841
9	40.0000E-9	8.7101E+0	1.1240E-3	31020842	40.0000E-9	8.3476E+0	1.1189E-3	31020841
10	45.0000E-9	9.0294E+0	1.1240E-3	31020842	45.0000E-9	8.8836E+0	1.1189E-3	31020841
11	50.0000E-9	9.3959E+0	1.1239E-3	31020842	50.0000E-9	9.2236E+0	1.1189	
12	55.0000E-9	9.5666E+0	1.1239E-3	31020842	55.0000E-9	9.5377E+0	1.1188	
13	60.0000E-9	9.6770E+0	1.1239E-3	31020842	60.0000E-9	9.6386E+0	1.1188	
14	65.0000E-9	9.8300E+0	1.1239E-3	31020842	65.0000E-9	9.8014E+0	1.1188	
15	70.0000E-9	10.0199E+0	1.1239E-3	31020842	70.0000E-9	9.9267E+0	1.1188	
16	75.0000E-9	10.0773E+0	1.1239E-3	31020842	75.0000E-9	10.0391E+0	1.1188E-3	
17	80.0000E-9	10.0626E+0	1.1239E-3	31020842	80.0000E-9	10.0506E+0	1.1188E-3	31020841
18	85.0000E-9	10.0979E+0	1.1239E-3	31020842	85.0000E-9	10.0694E+0	1.1188E-3	31020841

Status:
Ch1
Meas V 10V
Meas I 1mA
+I Meas Overflow
Waveform
RPM
LLEC Enabled
LLEC Met

Status codes

Each measurement includes an 8-digit status code. Assign the following letters to the code and use the following table to determine status:

A B C D E F G H

In the figure shown in PMU measurement status (on page 43), the circled status code is 11010021:

A. 1 = LLEC failed, sweep not skipped (yellow indicates that LLEC failed)

B. 1 = RPM being used

C. 0 = Not applicable (always 0)

D. 1 = Spot mean measurement type

E. 0 = Source not in compliance, no threshold reached

F. 0 = No measurement overflows

G. 2 = 10 µA measure range

H. 1 = Channel 1, 10 V measure range

PMU measurement status codes

Code letter	Summary or description	Value
A	Load-line effect compensation (LLEC) and sweep	0 = LLEC disabled, sweep not skipped
		1 = LLEC failed, sweep not skipped
		3 = LLEC successful, sweep not skipped
		4 = LLEC disabled, sweep skipped
		5 = LLEC failed, sweep skipped
		7 = LLEC successful, sweep skipped
B	RPM mode settings	0 = No RPM
		1 = RPM
		2 = Bypass; PMU
		3 = Bypass; SMU
		4 = Bypass; CVU
C	Reserved for future use	Always 0
D	Measurement type	1 = Spot mean
		2 = Waveform
E	Current threshold, voltage threshold, power threshold, and source compliance	0 = None
		1 = Source compliance
		2 = Current threshold reached or surpassed
		4 = Voltage threshold reached or surpassed
		8 = Power threshold reached or surpassed
F	Voltage measure overflow and current measure overflow	0 = No overflow
		1 = Negative voltage overflow
		2 = Positive voltage overflow
		4 = Negative current overflow
		5 = Negative voltage and negative current overflow
		6 = Positive voltage and negative current overflow
		8 = Positive current overflow
		9 = Negative voltage and positive current overflow
		A = Positive voltage and positive current overflow
G	Current measure range	0 = 100 nA (RPM only)
		1 = 1 µA (RPM only)
		2 = 10 µA (RPM only)
		3 = 100 µA
		4 = 1 mA (RPM only)
		5 = 10 mA
		6 = 200 mA
		7 = 800 mA
H	Channel number and voltage measure range	1 = Ch1, 10 V
		2 = Ch2, 10 V
		5 = Ch1, 40 V
		6 = Ch2, 40 V

Compensation Short Connection

Use to enable or disable short connection compensation. Refer to PMU connection compensation (on page 20) for details on setting up and using connection compensation.

Load Line Effect Compensation

Use to enable or disable load-line effect compensation (LLEC). Refer to Load-line effect compensation (LLEC) for the PMU (on page 23) for details on setting up and using load-line effect compensation.

DUT Resistance (R DUT)

The DUT resistance value. Refer to DUT resistance determines pulse voltage across DUT (on page 92) for details on calculating DUT resistance.

Max Voltage Estimator

The Maximum Voltage Estimator is a tool that enables you to calculate the maximum voltage and current based on the selected voltage range and the DUT resistance value you type in. The estimator does not affect the pulse output.

For a more accurate maximum voltage estimate, add the interconnect resistance to the DUT resistance value. The typical resistance of a white SMA cable is 0.75 Ω and the typical prober pin-to-pad resistance is 1 Ω to 3 Ω. Poor pin-to-pad contacts could be in the range of 10 Ω to 15 Ω.

The V Max and I Max values are valid with LLEC enabled or disabled. It is the maximum output of the PMU. The LLEC does not change the maximum output voltage or current of the PMU.

Threshold Current

The current threshold allows you to set a threshold. If the threshold is reached or exceeded, the present sweep is stopped. Testing continues with any subsequent sweeps.

This threshold is a comparison of the measurement after the pulse has been applied to the DUT (the threshold value will be exceeded, at least slightly). The degree to which the signal exceeds the threshold before the threshold is triggered is a function of the DUT response and test configuration. Generally, smaller voltage step sizes will reduce the amount that the signal exceeds the threshold. You can specify more than one threshold for each channel.

Threshold Voltage

The voltage threshold allows you to set a voltage threshold. If the threshold is reached or exceeded, the present sweep is stopped. Testing continues with any subsequent sweeps.

This threshold is a comparison of the measurement after the pulse has been applied to the DUT (the threshold value will be exceeded, at least slightly). The degree to which the signal exceeds the threshold before the threshold is triggered is a function of the DUT response and test configuration. Generally, smaller voltage step sizes will reduce the amount that the signal exceeds the threshold. You can specify more than one threshold for each channel.

Threshold Power

The power threshold allows you to set a power threshold. If the threshold is reached or exceeded, the present sweep is stopped. Testing continues with any subsequent sweeps.

This threshold is a comparison of the measurement after the pulse has been applied to the DUT (the threshold value will be exceeded, at least slightly). The degree to which the signal exceeds the threshold before the threshold is triggered is a function of the DUT response and test configuration. Generally, smaller voltage step sizes will reduce the amount that the signal exceeds the threshold. You can specify more than one threshold for each channel.

On the 40 V range, you may see the error message, "Pulse waveform configuration exceeded output power limits." To solve this issue, try increasing the period or using the 10 V range.

PMU Test Settings

The settings that are available for PMU tests are described in the following topics.

Pulse Settings

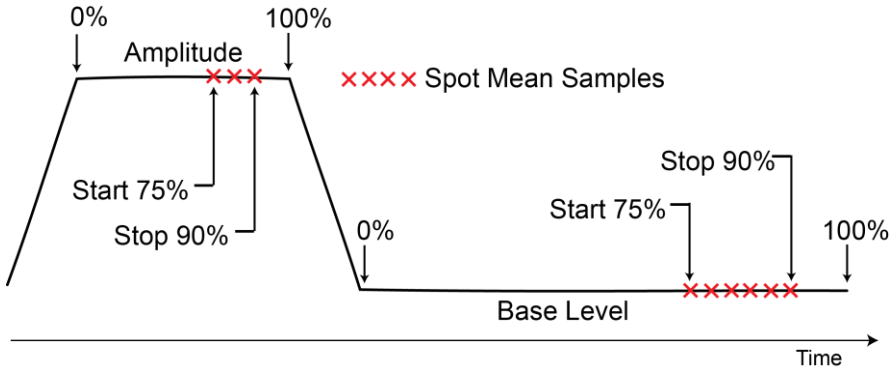
Under Pulse Settings, you can select the type of pulse test, how measured pulse values are handled, and the number of pulses.

Test Mode (PMU)

The Test Mode selects the type of pulse test. You can select:

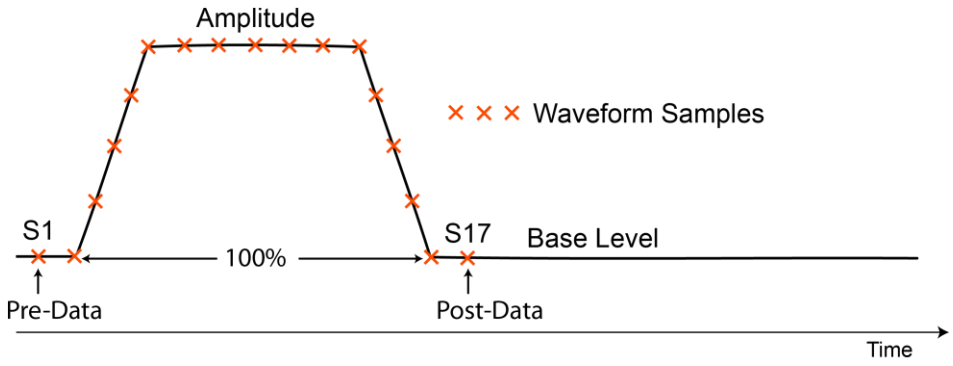
- **Pulse IV:** This test mode performs spot mean measurements (V or I) of the amplitude or base portions of one or more pulses. Typically, current versus voltage is graphed in the Analyze graph. The `pmu-iv-sweep` project provides an example of a pulse drain family of curves using the pulse test mode.
- **Waveform Capture:** This test mode samples the entire waveform. The waveform is graphed (voltage and/or current versus time) in the Analyze graph. The `pmu-1ch-wfm` project provides an example of a waveform capture. Note that the Timing Sweep Step option (in the Advanced dialog) is disabled when Waveform Capture is selected.

For pulse I-V, spot mean measurements are made on pulse amplitude and base level. You can measure voltage and current. The following figure shows the measure windows for spot mean measurements. The start measure and stop measure points for ITMs are fixed at 75 percent and 90 percent for both amplitude and base level.



The number of measurement samples that are made is relative to the widths of the magnitude and base level. For example, if the width of the magnitude is 1 µs, the measure window is 750 ns to 900 ns. If the width of the base level is 2 µs, the measure window is 1500 ns to 1800 ns.

For waveform capture, measurement samples are acquired on pulse rise, pulse amplitude, pulse fall, and a small portion before the rise (pre-data) and after the fall (post-data) on the base level, as shown in the following figure.



For details on spot mean measurements, refer to Spot mean measurements (on page 101). For user test module (UTM) programming, refer to the `pulse_meas_sm` function.

For details on waveform measurements, refer to Waveform measurements (on page 102). For UTM programming, the `pulse_meas_wfm` function is used to configure waveform measurements.

For UTMs, the `pulse_meas_timing` function allows you to adjust the measure window for the pulse I-V test mode or the pre-data and post-data settings for the waveform measurements. For ITMs, the measure window and pre-data and post-data settings are fixed.

Function descriptions are provided in *Model 4200A-SCS LPT Library Programming*.

Measure Mode

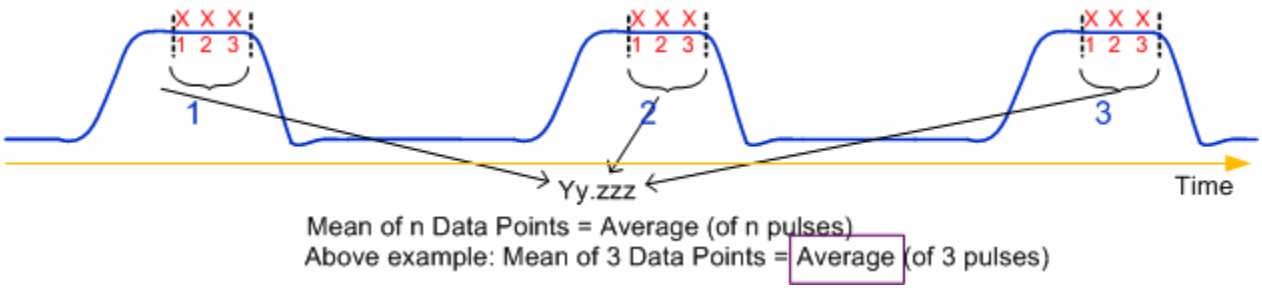
For Measure Mode, you can select Average Pulses or Discrete Pulses.

When Average Pulses is selected for Pulse IV, the measured values of two or more pulses are averaged. See the Pulse IV (Average pulses) measurement example (on page 49). For Waveform Capture, select Average Pulses to average each sample in the waveform with the same point in subsequent waveforms, for each pulse specified by the number of pulses.

When Discrete Pulses is selected for Pulse IV, the measured value of each pulse is acquired. Refer to the Pulse IV (Discrete pulses) measurement example (on page 50). For Waveform Capture, each sample for every waveform is recorded in the Analyze sheet. Refer to the Waveform Capture (Discrete Pulses) measurement example (on page 51).

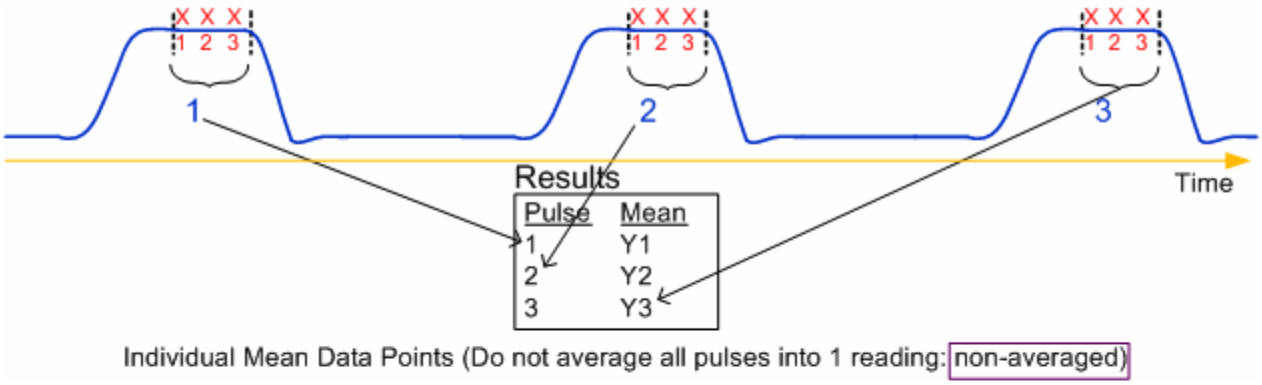
Pulse I-V (Average pulses) measurement example

For the example shown in the following figure, the mean of three pulses is averaged into a single reading (also called a spot mean). One averaged reading is yielded for each pulse. The result of the three averaged readings is placed in the Analyze sheet.



Pulse I-V (Discrete pulses) measurement example

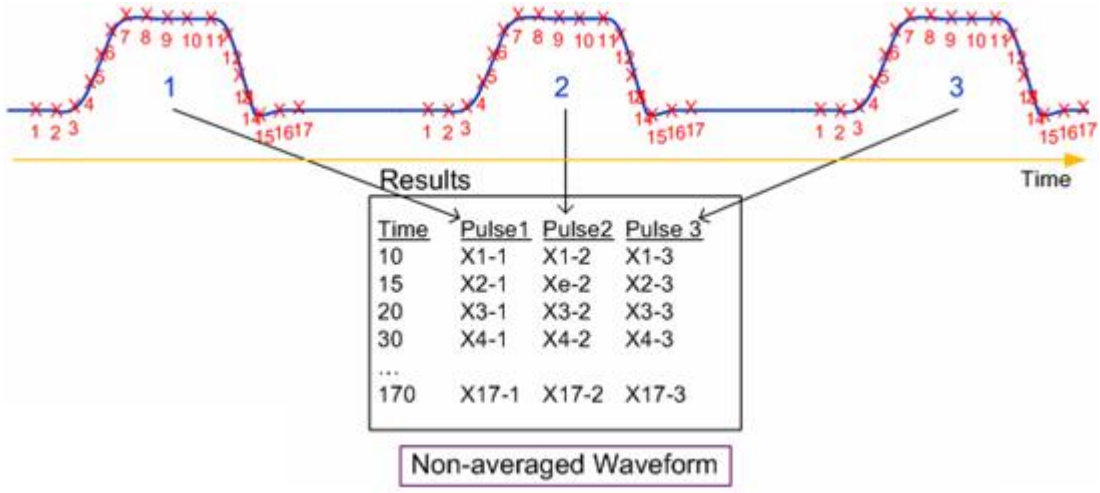
For the example shown in the following figure, the readings are the result of a pulse I-V sweep from 2 V to 5 V (in 1 V steps) with the discrete number of pulses set to three. This test yields the spot mean of the three pulses for each step of the sweep. The Analyze sheet for the 12 readings are also included in the following figure.



	A	B
1	ASMVHI	ASMIHI
2	1.9326E+0	1.9520E-3
3	1.9330E+0	1.9523E-3
4	1.9327E+0	1.9523E-3
5	2.9023E+0	2.9286E-3
6	2.9028E+0	2.9285E-3
7	2.9026E+0	2.9284E-3
8	3.8683E+0	3.9021E-3
9	3.8685E+0	3.9023E-3
10	3.8680E+0	3.9019E-3
11	4.8338E+0	4.8765E-3
12	4.8339E+0	4.8770E-3
13	4.8339E+0	4.8769E-3

Waveform Capture (Discrete Pulses) measurement example

For the example shown in the following figure, the samples of three pulses are captured. The 51 samples (17 samples x 3 pulses) are placed in the Analyze sheet.



Number of Pulses

The number of pulses for the PMU channel to output and measure for each step in the sweep (1 to 10,000). If you enabled autorange, load-line effect compensation (LLEC), or thresholds, the number of pulses is output multiple times for each step in a sweep.

Sweep Master

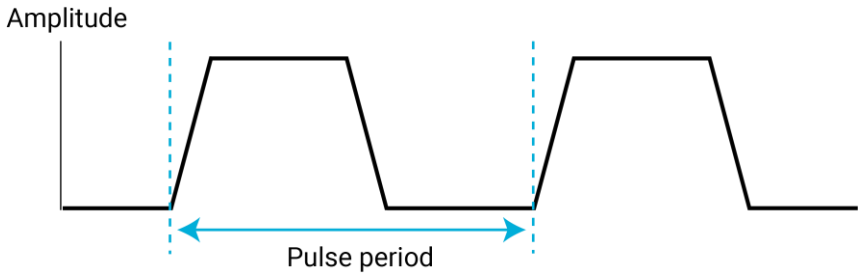
If there are multiple steps or sweeps in a test, use this to designate which instrument is the master. Refer to Step or sweep multiple device terminals in the same test (on page 68) for details.

Timing Parameters

The Timing Parameters group in the Test Settings tab allows you to set up the timing for the test. These parameters are described in the following topics.

Period

The pulse period is the time interval between the start of the rising transition edge of consecutive output pulses, as shown in the following figure. To minimize self-heating effects, set a pulse period that is 10 to 100 times longer than the pulse width to produce a duty cycle that is 1 percent to 10 percent.

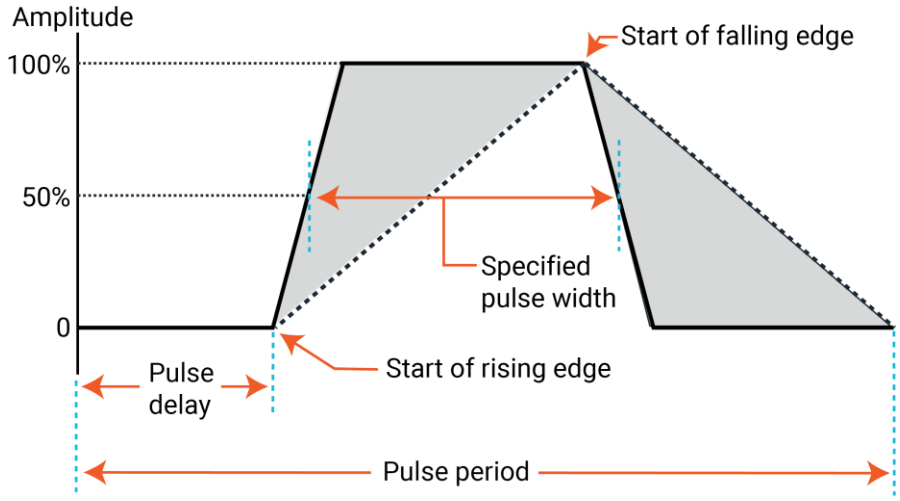


Width

The pulse width is the interval between the rising-edge and falling-edge medians. For a pulse with fast edges (a short transition time), the pulse width is essentially equal to the interval from the start of the rising edge to the start of the falling edge.

Rise and fall times are set independently. The pulse width is not affected by a change to the transition time. However, start points may shift with changes in transition time.

The dashed line pulse in the following figure shows how increased transition time can affect the rising edge and falling edge of the pulse. The shaded areas of the pulse show the changes in the slopes. Notice that the pulse width interval is not affected. If the transition time is increased, the pulse would not reach its programmed amplitude (100%).



Rise Time

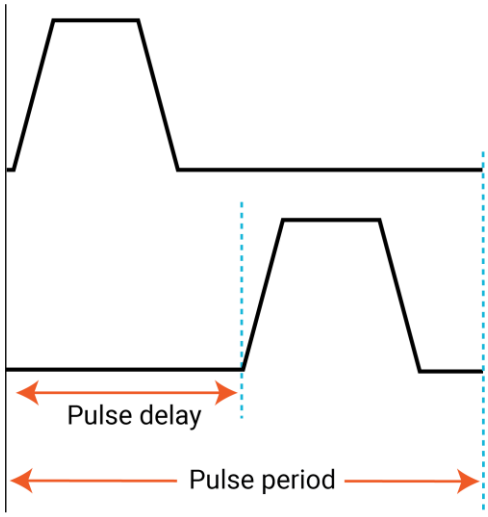
The rise transition time for the pulse output.

Fall Time

The fall transition time for the pulse output.

Pulse Delay

The pulse delay is the time interval between the start of the rising pulse edge of the trigger output pulse and the output pulse, as shown in the following figure. You can set the rising or falling polarity of the trigger output pulse edge to the output pulse. The pulse delay has a variable delay with respect to the trigger output.



NOTE

If you are using waveform capture in an ITM test, provide an initial delay that is at least as long as the shortest timing parameter (rise time, pulse width, or fall time).

Formulator

Opens the Formulator. The Formulator allows you to make data calculations on test data and on the results of other Formulator calculations.

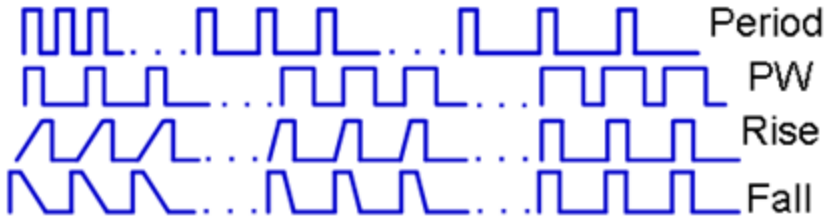
Refer to “The Formulator” in the *Model 4200A-SCS Clarius User Manual* for details on using the Formulator.

Output Values

If you are using subsites, each time a subsite is cycled, the measurements for the selected Output Values are placed in the Analyze sheet for the subsite. For example, if the subsite is cycled five times, there will be five measured readings (Output Values) for the test. For details, see “Cycle a subsite” in the *Model 4200A-SCS Clarius User Manual*.

Stepping and sweeping examples

The following figure shows parameter stepping and sweeping examples. In these examples, the Number of Pulses parameter is set to 3, so there are three pulses per period.



- **Period:** The pulse period steps or sweeps from a short period to a long period (or from a long period to a short period).
- **PW:** The pulse width (PW) steps or sweeps from a short pulse width to a long pulse width (or from a long width to a short width).
- **Rise:** The pulse rise time steps or sweeps from a long rise time to a short rise time (or from a long rise time to a short rise time).
- **Fall:** The pulse fall time steps or sweeps from a long fall time to a short fall time (or from a long fall time to a short fall time).

In the figure above, the ellipsis (...) between each burst of pulses indicates additional time that the pulse channel is outputting 0 V DC (the pulse channel is not pulsing). This time allows for analog-to-digital (A/D) sample processing and, if enabled, measure ranging and LLEC. For more information on LLEC, see How LLEC adjusts pulse output to the target levels (on page 25).

PMU Advanced Test Settings

To access these settings, on the Test Settings tab, select **Advanced**.

The Pulse Settings and Timing Parameters are described in the PMU Test Settings (on page 47).

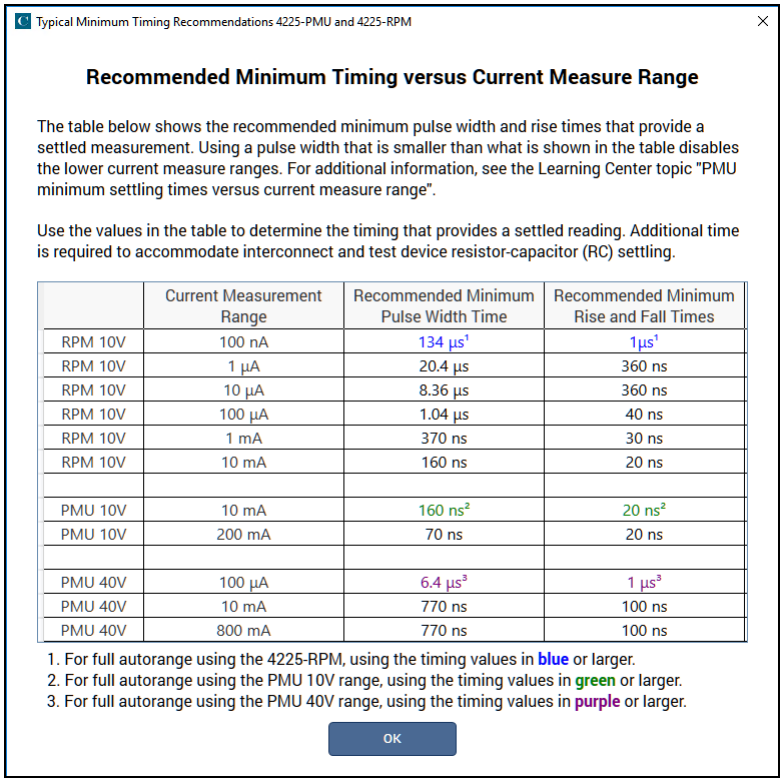
The Timing Sweep determines which timing parameters control the step or sweep. You can only step the timing parameters if the Operation Mode is set to pulse sweep or pulse train and if the Test Mode is set to Pulse IV. You can only sweep the timing parameters if the Operation Mode is set to pulse step or pulse train.

The Timing Sweep Step option is disabled when Waveform Capture is selected.

Settling Times

The settling time is the time that it takes for pulse levels to stabilize after the voltage or current is changed, such as during execution of a sweep.

The Typical Minimum Timing Recommendations dialog displays typical minimum timing versus current measure range recommendations. An example is shown in the following figure. These are the recommended minimums for each current measure range. Longer times may be required to accommodate DUT and interconnect settling.



When using autorange with an RPM connected, use the timing values on the top row (or longer/slower values). If using limited autorange, start with the timing values for that range.

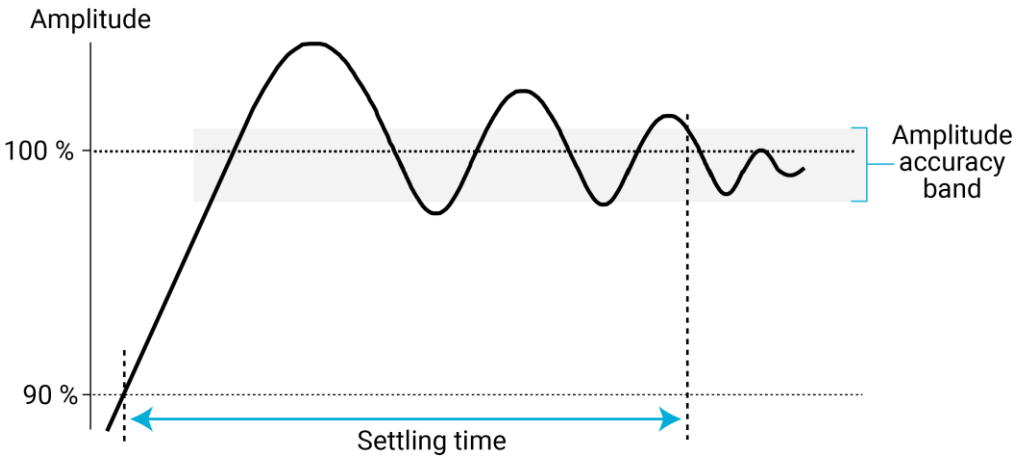
NOTE

If pulse width or period timing parameters are too narrow for a chosen measure range, a message is displayed showing the change to the current measure range for each effected channel. To avoid these changes, follow the guidelines shown in the previous figure. See PMU minimum settling times versus current measure range (on page 56) for more information.

Settling time includes the following τ (tau) time constants:

- **τInstrument:** Varies mainly with current range.
- **τSystem:** Due to cables, switches, and probers.
- **τDUT (Device Under Test):** Due to the implicit characteristics of the DUT.
- **τDielectric Absorption:** An issue only on the low current ranges.

Settling time is measured from the 90 percent point on the rising edge to the point where the pulse level remains in the accuracy band, as shown in the following figure.



PMU minimum settling times versus current measure range

The PMU and RPM current measure ranges require time to reach a settled value. The amount of settling time that is required increases for the lower current measure ranges.

You can set the pulse timing parameters (pulse width, rise, and fall) to any valid values and are independent from the recommended minimum timing values required to obtain settled readings. If the chosen pulse width is too narrow, the lower current measure ranges are not available. The timing of the pulse top and pulse base is used, along with the minimum timing in the chart to determine which current measure ranges are available.

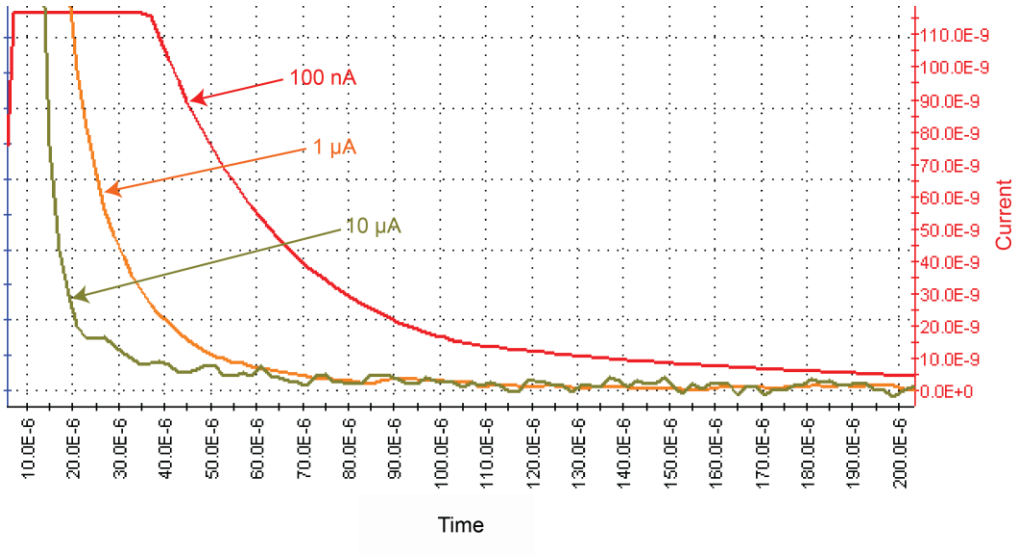
In ITMs, when you modify the PMU timing settings in the Advanced Test Settings, if you make a pulse timing change that affects the measure range of a PMU channel, a message noting the unavailable ranges is displayed. You should check the recommended pulse width and period for the measure ranges noted in the message. When setting the PMU force measure options, if a timing parameter prevents use of one or more PMU or RPM measure ranges, the note in the center of the window turns red and lists the unavailable ranges. Access the PMU force measure options by selecting the FORCE MEASURE button.

The Typical Minimum Timing Recommendations dialog shows the recommended minimum pulse widths and transition (rise and fall) times for each current measurement range. These times are the minimum time necessary for the PMU, or PMU with RPM, to reach a settled value (into an open). Additional time must be entered to account for DUT settling time, usually due to RC effects.

If you need to use autoranging with the RPM, note that the appropriate minimum timing values are the first row in the table. Note that the pulse timing values are not altered during the test, unless a time sweep or time step is configured. This means that the pulse width is not changed as the measure range changes. When using autoranging or limited autoranging, choose the recommended minimum timing values for the lowest chosen measure range.

You can override the settled measurement requirement for the PMU or PMU+RPM measurements. In the Clarius My Settings, Environment Settings, select **PMU: Allow unsettled measurements**.

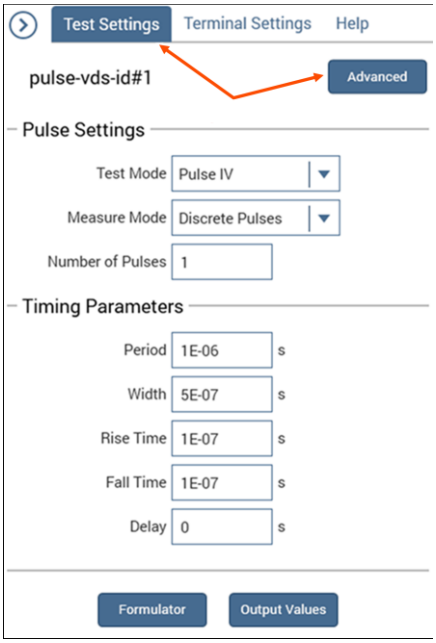
The following figure contains a graph of the current signal settling time of three current measure ranges of the 4225-RPM. The graph shows the settling time of a 1 V amplitude pulse in to an open (high impedance) with a 300 ms pulse width and a 1 ms transition time. Note that this figure does not show the voltage signal.



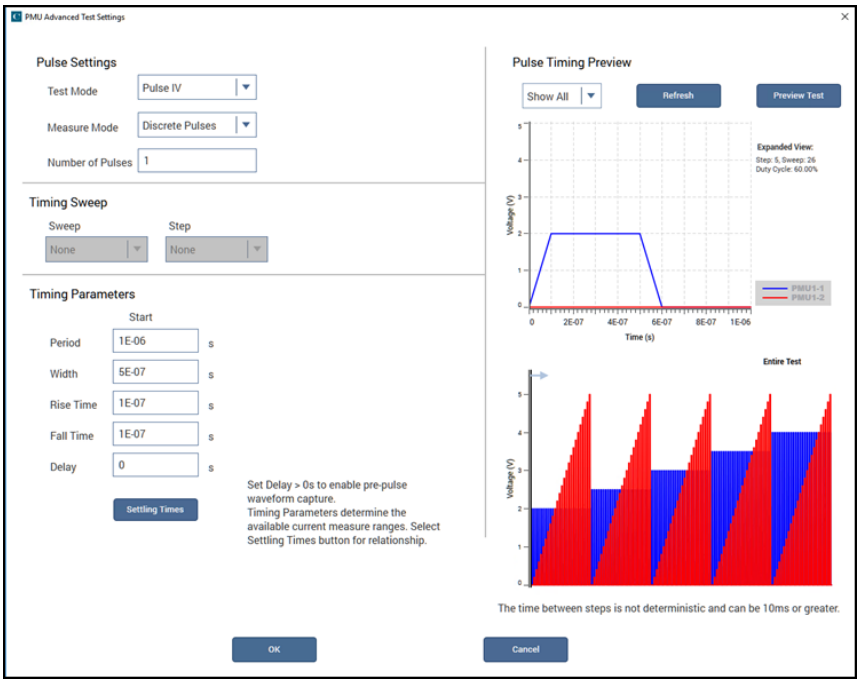
PMU pulse timing preview

Before executing an ITM test, you can preview a waveform generated using the settings. This can help you understand the behaviors of the test settings without applying signals to the test device. The Pulse Timing Preview is in the PMU Advanced Test Settings dialog.

To open the PMU Advanced Test Settings dialog, select **Test Settings**, then **Advanced**, as shown in the following figure.



An example is shown in the following figure.



The preview displays representations of the waveforms for the different PMU channels in the test. The illustrated pulse waveforms are defined by the Pulse Timing settings for the specific PMU. This preview provides a representation of parameter values (no signals are output to the test device). It is not intended to be a strict definition of the actual number of pulses or pulse voltages to be applied to the device under test (DUT). When the actual test is running, the actual number of pulses or pulse voltages may be different than the preview.

Enabling current measure ranging or load-line effect compensation (LLEC) requires pulses that are in addition to what is shown in the preview. To learn how the PMU handles DUT load variation and measure ranging during a test, refer to How LLEC adjusts pulse output to the target levels (on page 25).

You can zoom in or out of the view in the Extended View and Entire graphs as follows:

- Use the cursor to define an area to zoom into. The area is magnified when the area is released.
- Double-click or select **Refresh** to restore the magnification to the initial view.

Each channel has a unique color.

The gaps between the pulse waveforms in the Entire Test graph indicate the time between sweep points where the PMU performs calculations for the test while the pulse channels output 0 V. To learn more about how these gaps relate to how the PMU handles DUT load variation and measure ranging during a test, see How LLEC adjusts pulse output to the target levels (on page 25).

It is possible to have a test with too many pulses to be suitably graphed. This may be from too many pulses from a large number of sweep points or step points, or a large number of pulses. In this case, the message “Too many pulses to graph” is shown on the Entire Test graph. The test will still run. If you select OK on the PMU Advanced Test Settings dialog and it does not generate any warning or error messages, the test is valid and runs even if the entire test waveform cannot be displayed on the preview graphs.

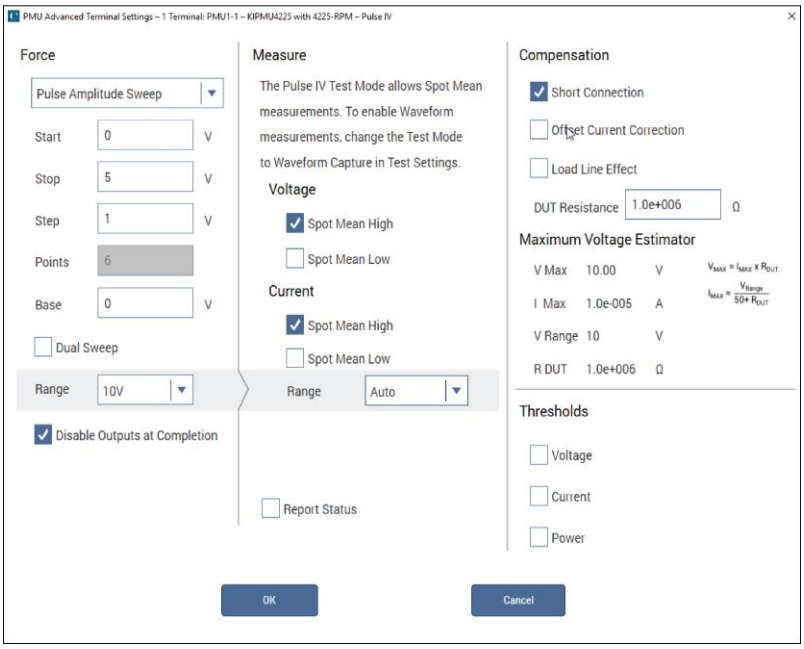
NOTE

For the 40 V range for the 4220-PGU and 4225-PMU in pulse mode, the pulse generator is limited to slew no more than 160 MV/s when pulsing more than 10 s.

Review the following examples to understand the Pulse Timing Preview feature.

PMU amplitude sweep example (one-channel)

This figure illustrates the advanced terminal settings for a pulse amplitude sweep using a single PMU channel.



The following figure illustrates the Advanced Test Settings for a six-step pulse amplitude sweep. In this sweep, the PMU Advanced Terminal Settings dialog (see previous figure) defines the test parameters.



In the Pulse Timing Preview, there are two graphs. The bottom graph, labeled “Entire Test,” shows the complete test. This graph shows each sweep and step point for the entire test. The graphed points reflect the PMU Advanced Settings for the PMU channel in the test. The cursor (the pair of vertical black lines on the Entire Test graph) defines the content of the upper graph labeled “Expanded View”). The test settings shown in the previous figure define the six sweep points that are shown in the bottom graph of the following figure as six pulse periods. In this example, the pulse periods have voltage amplitudes that increase from 0 V to 5 V.

The graph labeled “Expanded View” provides in-depth information on the section designated by the cursor lines on the Entire Test graph. The graphed points reflect the timing parameters (Pulse Timing Preview) and settings from the PMU Advanced Settings dialog for each PMU channel in the test, but only for the area specified by the cursor.

Select **Preview Test** to animate the waveform. The cursor moves from left to right on the bottom graph while displaying the point waveform of each sweep within the cursor on the top graph.

NOTE

Selecting **Preview Test** does not output any pulses, but it does illustrate how the test will progress as a result of the test parameter settings.

PMU amplitude sweep and step example (two-channel)

In this two-channel example, one channel is sweeping while the other channel is stepping. The sweeping channel is performing pulse amplitude sweeps with nine sweep points. On each inner loop, PMU1-2 sweeps 0 V through 4 V in 0.5 V increments. The stepping channel is performing pulse amplitude steps with four step points. On the outer loop, PMU1-1 pulses the four steps of 1 V through 2.5 V in 0.5 V increments.

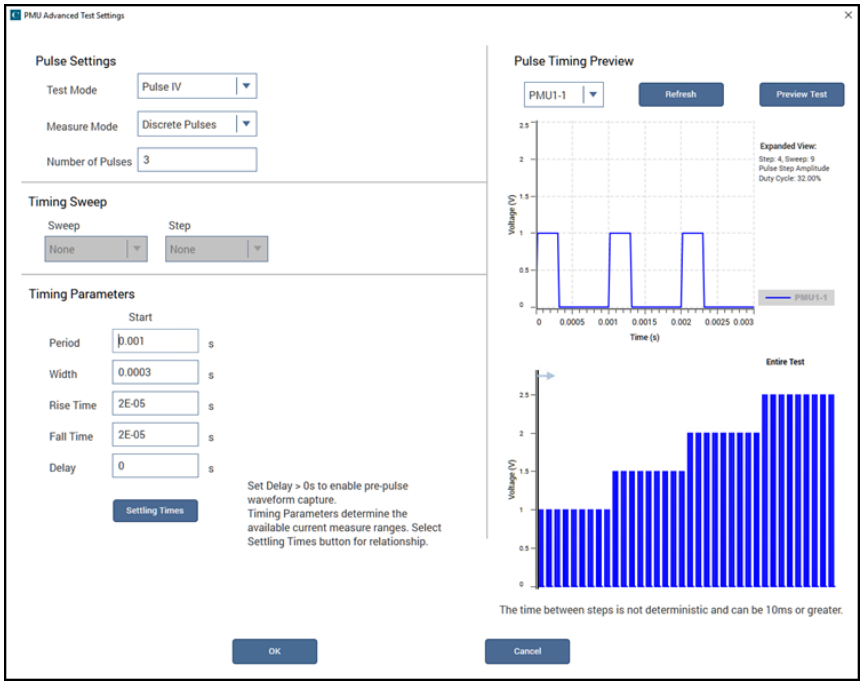
Terminal Settings for the following figure

	PMU1-1 (blue waveform)	**PMU1-2 (red waveform)**
Operation modes	Pulse Amplitude Step	Pulse Amplitude Sweep
Start Voltage	1	0
Stop Voltage	2.5	4
Step Voltage	0.5	0.5
Number of steps or sweep points	4 (automatically calculated)	9 (automatically calculated)

To preview the test, select the Test Settings tab, then select Advanced. Under Pulse Timing Preview, you can preview a single channel or all channels in the test. The following figure has Show All selected, which graphs all channels in the test. The Entire Test graph shows four steps of nine points each. The sweep and step count displays the position of the cursor in the overall test. This example has the Number of Pulses set to 1.

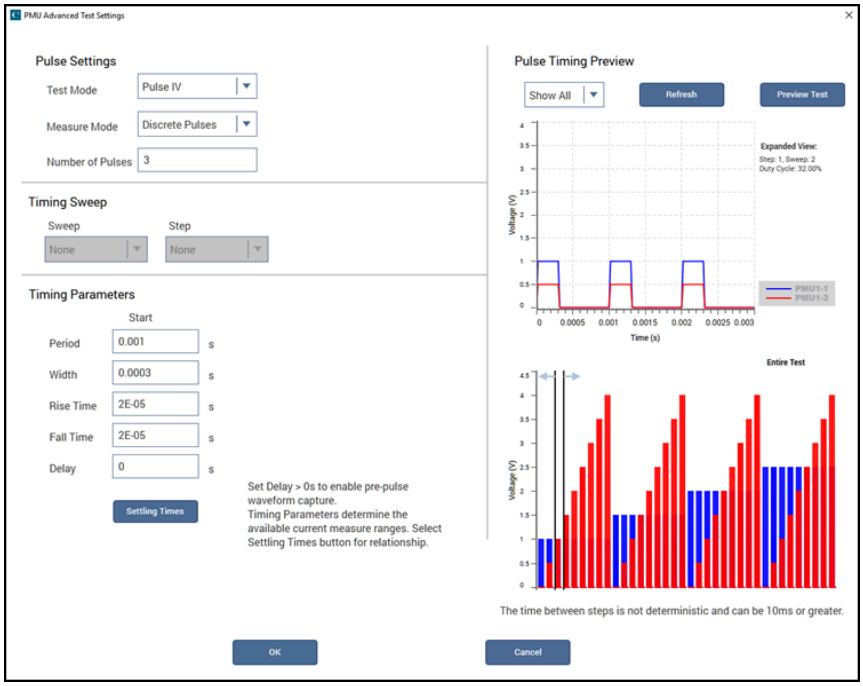


If you change the number of pulses to three (instead of one) and only display one channel (PMU1-1, instead of Show All), the preview of the waveform changes as shown in the following figure. Each point in the step now uses three periods, so there are three pulses shown in the Expanded View. In the Expanded View, the x-axis shows the time in seconds. This is three times longer than the Expanded View graph when the number of pulses is set to one, as shown in the previous figure.



If you configure the preview to all channels, both the sweeper and stepper are displayed for the three-pulse test, as shown in the following figure.

The Number of Pulses parameter determines the number of pulses that are output and measured for each attempted point in the sweep or step. The PMU amplitude sweep and step example (two-channel) test figure shows PMU1-1 (the stepper) with the number of pulses changed to three. Notice that each sweep point of the displayed waveform in the figure has three pulses (number of pulses set to three). Because the cursor in the lower graph always contains the complete waveform of each point in a test, the top graph shows the three pulses. The following figure shows both channels for the sweep and step test with the number of pulses set to three. Note that the value for the number of pulses does not affect the number of sweep or step points in the test.



Higher channel count test example

This example shows how to use the Pulse Timing Preview for tests with higher channel counts.

The following figure uses the key test parameters shown in the following table.

Operation mode and voltages for the four channels

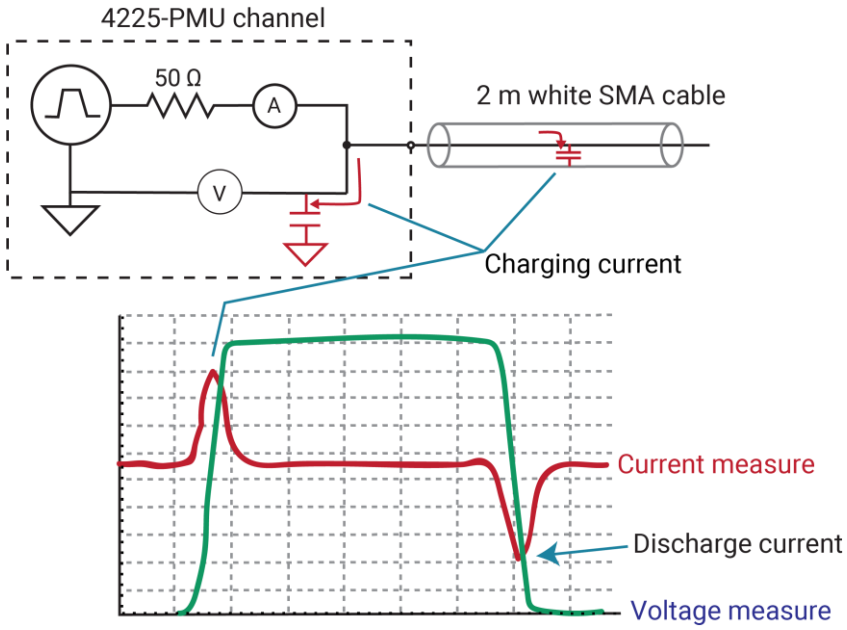
	PMU1-1	PMU1-2	PMU2-1	PMU2-2
Operation mode	**Pulse amplitude step**	**Pulse amplitude sweep**	**Pulse voltage train**	**Pulse voltage train**
Start or base voltage	1.5	0	1.5	0.5
Stop voltage	3	4	*	*
Step voltage	0.5	1	*	*
Number of points	4	5	*	*

* Not applicable. The pulse voltage trains are fixed pulse voltage levels; they do not vary during the sweep or step points.



PMU capacitive charging/discharging effects

During pulse transitions, the measured current charges and discharges the capacitance in the system (see following figure, red waveform). This system capacitance consists of the cable capacitance, PMU (with RPM, if connected) capacitance, and device capacitance. The following figure shows the pulse waveform showing capacitive charging and discharging current waveform in relation to the applied voltage waveform of the PMU connected to the supplied 2 m (6.5 ft) SMA cable (no DUT connected).



The setup used to generate these waveforms is shown in the previous figure, and also shows the capacitance and the charging effect (red arrows) seen during pulse transitions. This setup shows a single channel of a PMU, with the supplied 2 m (6.5 ft) white SMA cable connected to the channel output. Note that the other end of the SMA cable is open (no connection).

The current shown in the previous figure is measured by the PMU, but is not flowing through a device under test (DUT). The measured current is the sum of this charging or discharging current, as well as the current flowing through the DUT. This current is primarily caused by the capacitance in the cable and is described by the following equation:

$I = C * dV/dt$

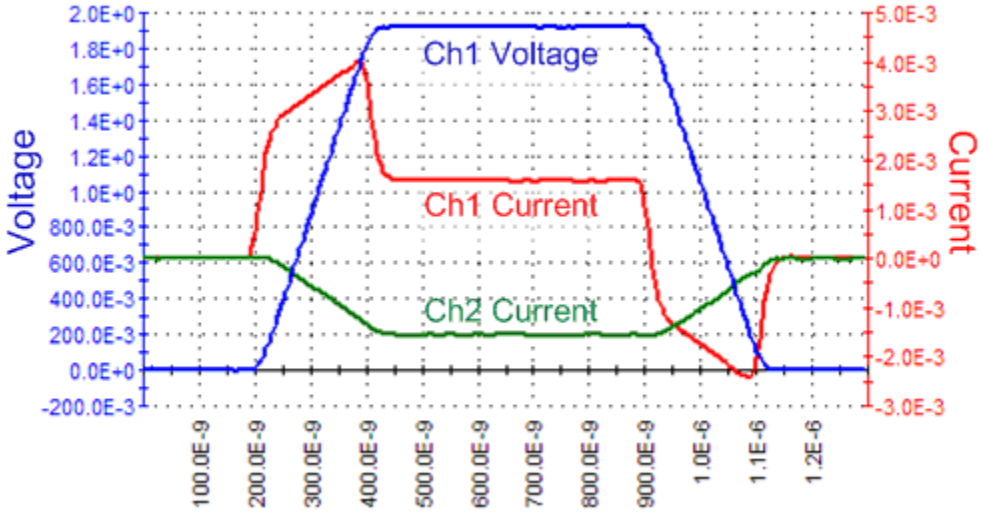
Where:

- I is the measured current
- C is the capacitance
- dV/dt is the pulse voltage amplitude divided by the rise (or fall) time

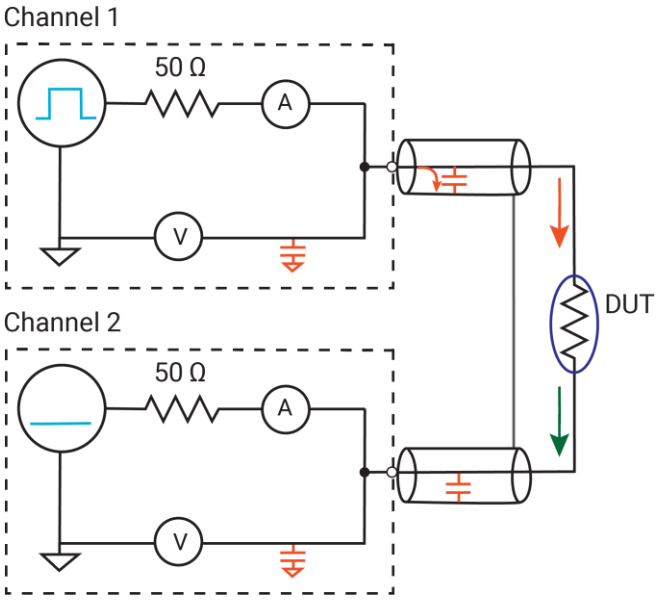
The equation shows that this effect is a function of the capacitance, as well as the dV/dt. Therefore, minimizing the capacitance will reduce this measurement artifact. The cabling is typically the largest contributor to the system capacitance. Slowing down the pulse transitions will also reduce the height of the current charging effect.

This capacitive charging current is primarily a measurement artifact, as the current does not flow through the DUT. Note that if a spot mean is taken during the settled portion of the pulse, then this charging does affect the spot mean measurement.

The following two figures show the waveforms and setup for a pulse test on a resistor DUT and illustrates a configuration to eliminate this artifact. The following figure shows that the channel 2 current waveform does not have this current charging artifact. This is because channel 2 is not pulsing, so dV/dt = 0. Using channel 2 in this configuration is sometimes called "low-side measurement." This measurement approach is useful when analysis of the current signal pulse transitions is required.



The previous figure shows the current waveforms for both PMU channel 1 (high side) and channel 2 (low side) current measurements. Note that channel 2 does not show the capacitive charging effects. Also, note that the channel 2 current measurement is negative because the current is flowing into channel 2.



In the previous figure, the voltage pulse is applied by channel 1; channel 2 does not pulse. Therefore, there is no dV/dt, and therefore there are no charging or discharging currents during the pulse transition. The red arrows show charging and DUT current for channel 1. The green arrow illustrates the DUT current only for channel 2.

PMU and RPM measure ranges are not source ranges

Unlike a source-measure unit (SMU), the PMU and RPM current measure ranges are measure ranges only, not source and measure ranges. For example, the SMU 10 mA measure range has a maximum source and measure value of ±10.5 mA, including the five percent overrange. The 10 mA measure range of the PMU 10 V range has a maximum measurement of about ±10 mA, but the full source capability of the 10 V source, which is ±200 mA. An alternate way to present this difference is that the SMU range has a source compliance equal to the measurement limit, but the PMU and RPM ranges have a source compliance larger than the measure range. Note that for the maximum PMU current measure ranges (200 mA for the 10 V range, 800 mA for the 40 V range), the source limit is the same as the measure limit, so the 200 mA and 800 mA ranges act similar to the SMU current range.

This measure-only limit is necessary for the best performance of the pulse when using the PMU alone or with the RPM. Generally, the purpose of a pulse measurement is to minimize the time required to make a measurement in order to minimize device self-heating or some other time-based device behavior.

To minimize the measurement time, the signal at the device under test (DUT) must get to the specified voltage level and settle as quickly as possible. A key aspect of this goal is handling the capacitive charging effects during the pulse transitions.

Since the interconnect and the DUT always have some capacitance, it is best to charge up this capacitance as quickly as possible. This can be done by allowing the maximum amount of current to flow into the capacitor during charging. This may cause an overflow for the measure range during transitions, especially on the lower RPM measure ranges. Note that the measurement range cannot be changed within a pulse, so a single measure range must be used for the entire pulse.

If the PMU or RPM was current limited to the measure range, the charging rate would require a longer time to reach a settled signal. With the maximum current available at all measure ranges, the signal will settle as fast as possible, allowing for a good DC-like current measurement using the shortest possible pulse. This is especially important at the lower current measure ranges, when the settled part of the pulse may have a signal level in the nA (or single µA) value, but the charging current is possibly tens of µA (or mA, respectively).

See PMU capacitive charging/discharging effects (on page 64) for information on the cause of the capacitive charging effect and how to work around it.

4220-PGU and 4225-PMU output limitations

In addition to the maximum output of the PMU and PGU instrument cards (see DUT resistance determines pulse voltage across DUT (on page 92)), the pulse instrument cards also have a limit for the number of large amplitude pulse transitions within a period. The 4200A-SCS system enforces limits on the quantity and amplitude of waveforms that the 4220-PGU and 4225-PMU may generate. A test exceeding these internal limits generates error code `-830`. To fix this problem, increase the pulse period, decrease the voltage amplitude, or both. For information on the pulse default values, see the `pulse_init` LPT command description.

Configure the PGU, PMU, and RPM using tests

To configure and control the PGU, a user test module (UTM) is needed. You can also use UTMs to configure and control the PMU and RPM preamplifier. For UTM programming, see “LPT commands for PGUs and PMUs” in *Model 4200A-SCS LPT Library Programming*.

You can use interactive test modules (ITMs) to configure and control a PMU and RPM preamplifier. Refer to “Configure a simple test” in *Model 4200A-SCS Clarius User Manual* for information on configuring an ITM for the PMU.

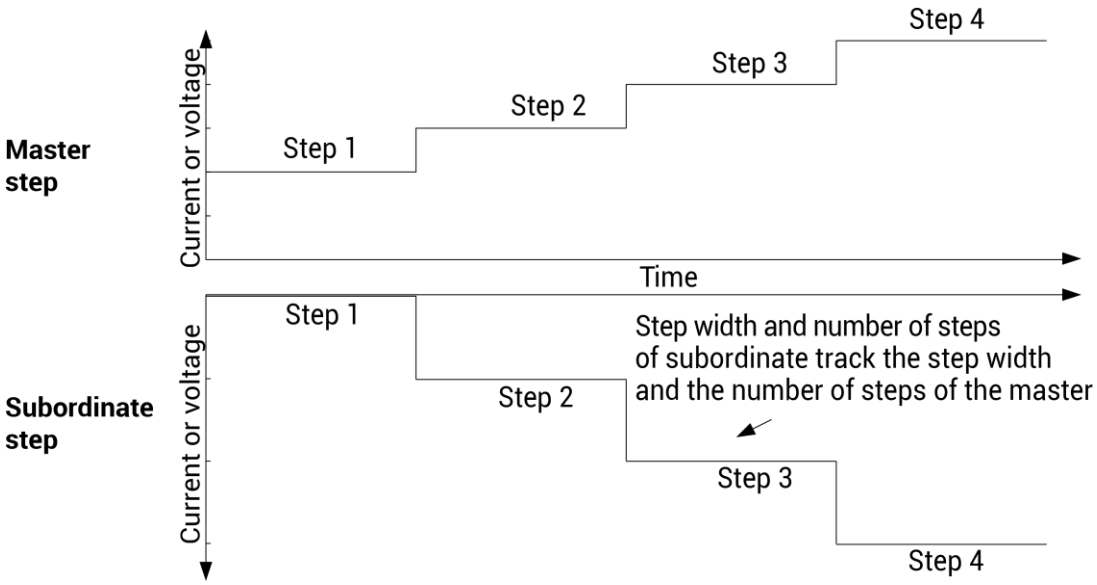
An ITM automatically controls the RPM based on the type of test (pulse, CV, SMU). RPM switching can only be controlled using the `rpm_config` LPT function in a UTM. For details, refer to Using the RPM as a switch (on page 9).

NOTE

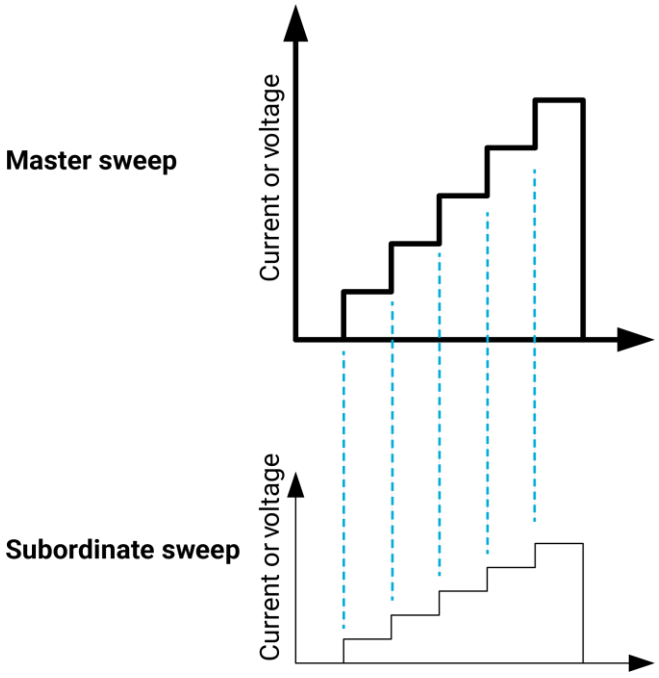
For automatic switching of the RPM in ITMs, the RPM must already have all instrument cabling connected and recognized by the system. Information on performing this update is in “Update the RPM configuration” in *Model 4200A-SCS Setup and Maintenance*.

Step or sweep multiple device terminals in the same test

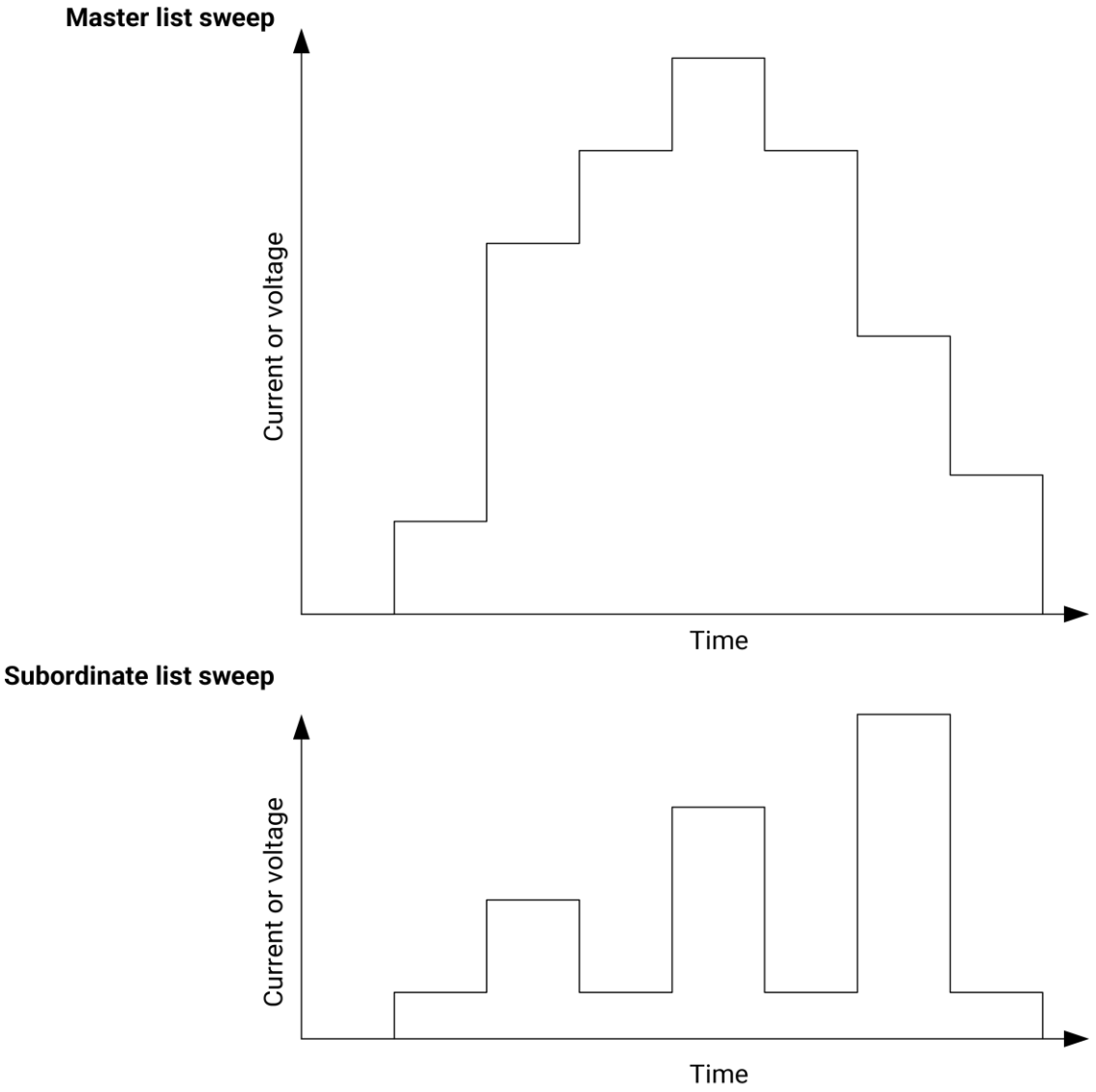
Multiple steps or sweeps in an interactive test module (ITM) must track with regard to step number and duration. For example, you might want to apply multiple steps to multiple device terminals, such as when stepping the biases on two transistor terminals and sweeping voltage or current on the third terminal. In this setup, Clarius automatically sets the step operations to occur simultaneously, with one terminal set up as the master. All other step functions are automatically designated as subordinates. The following figure illustrates this concept.



In the following figure, the step width and the number of steps of the subordinate track the step width and number of steps of the master sweep.



In the following figure, the step width and number of steps of the subordinate list sweep tracks the step width and the number of steps of the master list sweep.



If you do not specify an instrument to be the master, the first instrument that was assigned to the step or sweep operation mode is assigned to be the master. You can change this designation in the Test Settings pane.

When a master is set, Clarius sets the points and step size values for the subordinate terminal to be the same as the settings for the master terminal. You cannot change the subordinate points value for the subordinate terminal. For list sweeps, the number of points in the list items for the subordinate is changed to match the number of points in the master. If points are added to the master, the last point of the subordinate list is repeated. If points are removed from the master, the same number of points are removed from the end of the subordinate list.

You can have a dual sweep on a subordinate terminal even if the master is not set to dual sweep. In this case, the dual sweep of the subordinate terminal has a total number of steps equal to the number of steps in the master terminal. For example, if the master terminal is set to measure ten points, the subordinate dual sweep will measure five points on the first side of the sweep and five points on the second side of the dual sweep. If the master is set to an odd number of points, the subordinate terminal will repeat the measurement of the last sweep point.

The subordinate SMUs are not automatically set for dual sweep when Dual Sweep is enabled for the master SMU. Dual Sweep must be individually enabled for each SMU.

To specify the master sweep:

1. Select the test.
2. In the right pane, select **Test Settings**.
3. For **Sweep Master**, select the instrument that you want to designate as the master.

Basic troubleshooting procedure

If the test pulse I-V results do not meet expectations, use the following steps as a guide for troubleshooting. Because the pulse I-V results extract the spot mean measurements from the top of the pulse, good pulse I-V results require a reasonable pulse shape.

Step 1. Verify prober connections from the PMU or RPM to the DUT

1. Use cabling and connections optimized for high frequency (>150 MHz).
2. Connect the low side of the device under test (DUT) to the shield of the coaxial cable (see Shield connections (on page 3)), or connect the low side to another PMU or RPM channel (see Connections to prober or test fixture bulkhead connectors (on page 16) or Pulse I-V (Average pulses) measurement example (on page 49)).
3. Connect the shields (refer to the figure in Local sensing (on page 17) that shows four-terminal local sense connections).
4. If you are not using the supplied cabling, minimize the loop area created by the shield and center conductor. Do not use the GNDU connection for the return or ground path for any pulse I-V signal. Refer to Shield connections (on page 3).
5. Minimize the cable length. See Cable length (on page 4).

Step 2. Verify the pulse shape

To check that the pulse shape provides a flat, settled portion near the end of the pulse top:

1. Configure the test for Waveform Capture.
2. Ensure that voltage, current, and time waveforms are measured. See Waveform capture measurement configuration (on page 42).
3. Enable the status for each PMU channel in the test. See PMU - all terminal parameters (on page 37).
4. Select a voltage level for each channel that puts the device into the area of the curve that is questionable. If a large portion of the pulse I-V curve is under question, viewing the waveform shape at two or three different voltage levels may be necessary.
5. Configure the ranges to match the pulse I-V test.
6. Configure the connection and load-line effect compensation (LLEC). To match the pulse I-V test conditions, enabling LLEC allows the PMU to compensate for lower voltage levels at the test device when current is flowing. See Enable LLEC (on page 30).
7. Configure the graph with the time value on the x-axis, all voltage measurements on Y1, and current measurements on Y2. On the graph, select **Graph Settings** and select **Define Graph** to open the Graph Definition dialog. By default, the voltage waveforms are blue and use the left (Y1) axis; the current waveforms are red and use the right (Y2) axis.
8. Save the project.
9. Run the test and view the waveform on the graph. While viewing the graph, check that the voltage has a fairly flat top, without significant ringing or oscillations.

There may be current peaks during the pulse transitions. The peaks during the transitions are expected; see PMU capacitive charging/discharging effects (on page 64). The current waveform may show settling, but should not have significant ringing. An example of a good waveform shape is shown in PMU and RPM measure ranges are not source ranges (on page 67).

Due to interconnect and DUT settling time requirements, low current measurements (< ~10 mA) may require a wider pulse than the recommended minimum timing values. This is especially important for <1 mA level current measurements using the 4225-RPM. See PMU minimum settling times versus current measure range (on page 56)

A waveform graph may show a Measurement Overflow condition.

This overflow during the pulse transitions does not affect the spot mean measurements, because the spot mean is taken during the settled portion of the pulse top. Note that this error would not occur during pulse I-V, because the spot mean measurement window does not include the rising or falling edges of the pulse. Refer to Test Mode (PMU) (on page 48), PMU and RPM measure ranges are not source ranges (on page 67), and Measure Mode (on page 49) for more information.

Step 3. Is the pulse level correct for each channel?

1. If the pulse level is not correct for each channel, enable load-line effect compensation (LLEC). To compensate for the IR drop effect, the LLEC algorithm applies multiple pulses at each sweep step; make sure that the DUT behavior is not adversely affected by the LLEC approach.
2. Run the test again and compare results. If the results match the test settings, the issue was the lack of LLEC.

The load-line effect can reduce the voltage level at the DUT terminal when current is flowing. See Load-line effect compensation (LLEC) for the PMU (on page 23).

Refer to Step 4. Is the pulse I-V curve suspect? (on page 73) for examples with LLEC disabled and enabled.

Step 4. Is the pulse I-V curve suspect?

If the waveform has a good shape (Step 2. Verify the pulsed shape), and the pulsed level is correct (Step 3. Is the pulsed level correct for each channel?), but the pulse I-V curve is suspect, perform the steps below.

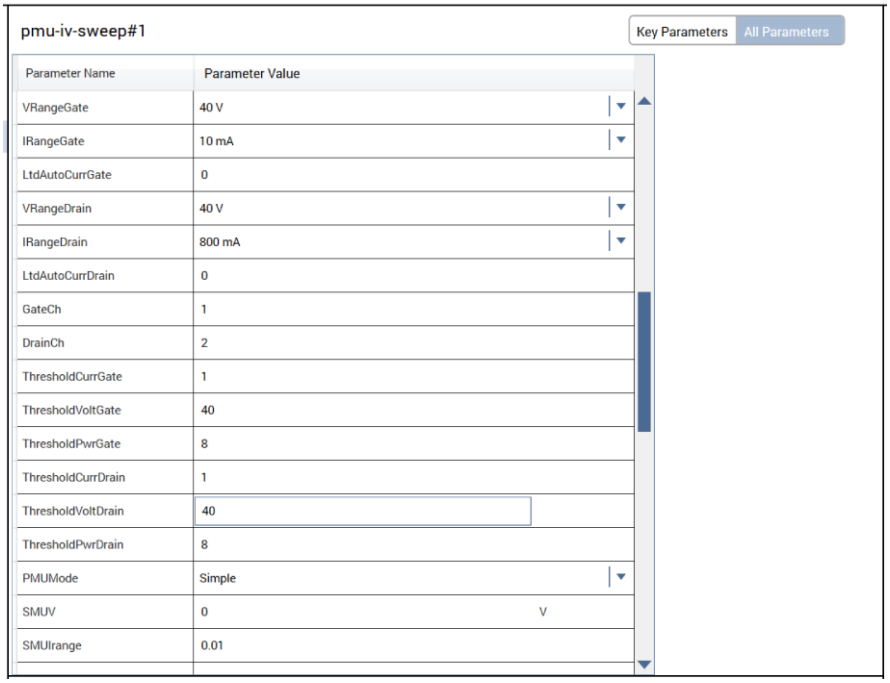
In this procedure, you set test parameters to provide boundaries for the test envelope. When load-line effect compensation (LLEC) is disabled, the source voltage must be bounded.

NOTE

LLEC may not respond properly for a high-gain transistor (for example, a compound semiconductor-based amplifier or power transistor).

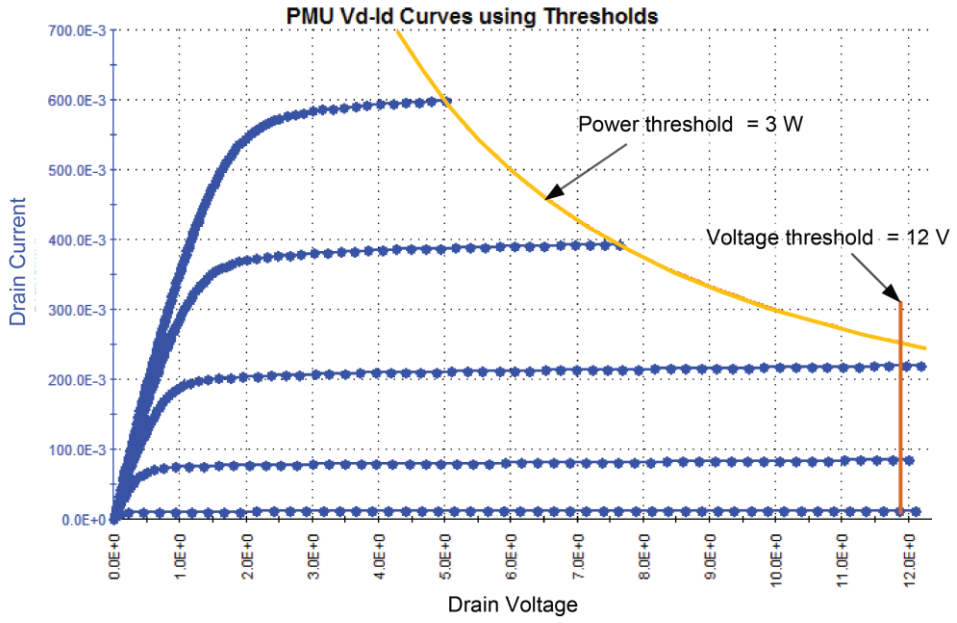
If the pulse I-V curve is suspect:

1. Disable the load line for the gate and drain in the Key Parameters. For an ITM, see Load-line effect compensation (on page 23).
2. Choose the maximum voltage for the selected source range. For example, many high-power transistors require fairly high voltages and currents, so the PMU 40 V source range is common.
3. Set the thresholds in the All Parameters pane (see following figure and PMU - all terminal parameters (on page 37) for more detail). Enter the maximum voltage for the DUT. For a transistor, set the `ThresholdVoltDrain` voltage for the maximum voltage for the drain.

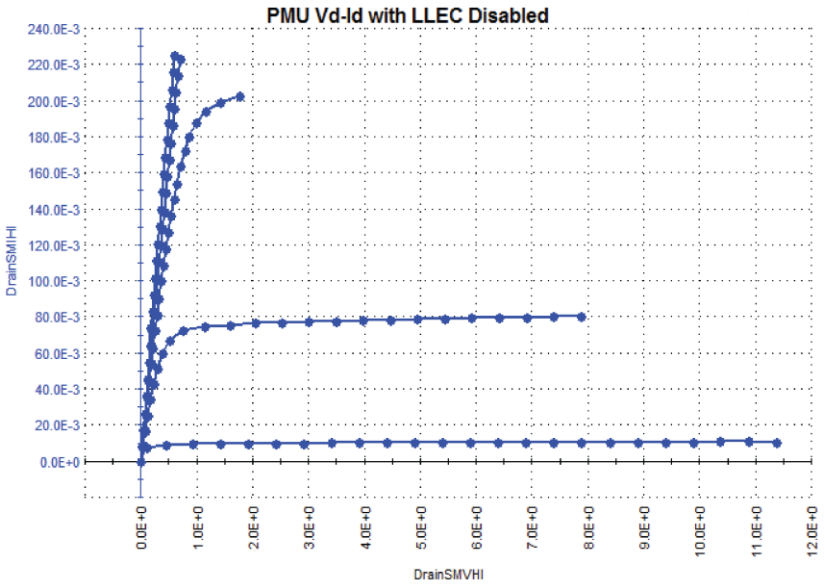


4. Enter the maximum power for the test device.

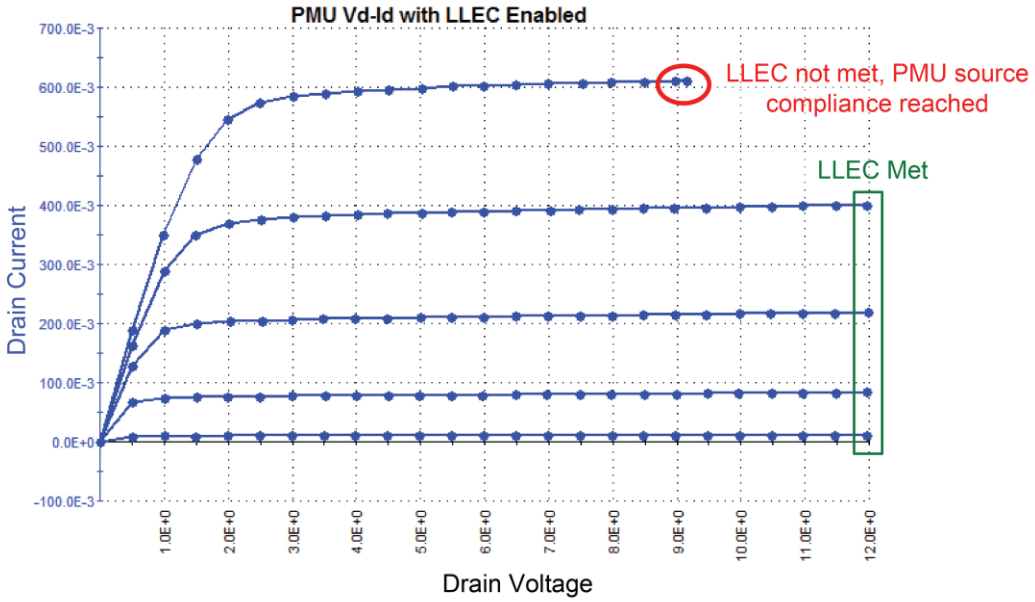
An example of a transistor test with LLEC disabled with a power threshold of 3 W and a voltage threshold of 12 V is shown in the following figure. Note that each threshold allows the test to be bounded. Also note that the thresholds do not stop the test at exactly the threshold value, but only after the threshold has been exceeded. One test point always exceeds the threshold. You can reduce the amount that the threshold is exceeded by using smaller sweep step sizes.



The following figure shows a family of curves from a fairly high-powered device with the load-line effect.



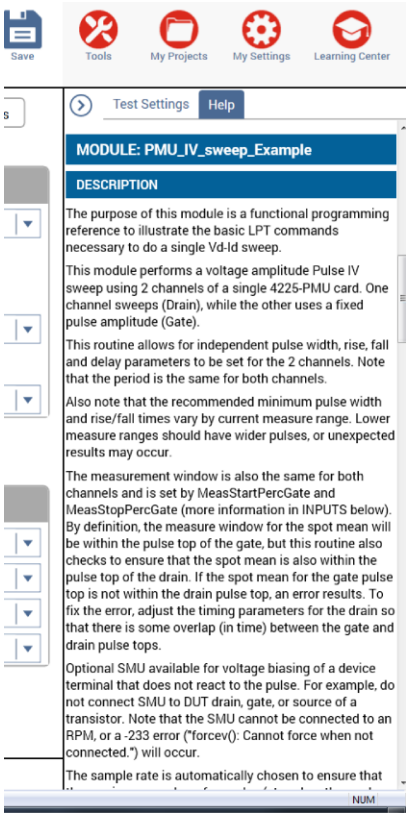
The following figure shows the same device tested with load-line effect compensation enabled. With LLEC enabled, the curves stop at the programmed V_d = 12 V. Note that the top curve, in the red circle, did not reach the 12 V setting. This is because the PMU 40 V source range reached source compliance. In this case, the PMU is at its limit and cannot source any more voltage or current to this particular resistance. See the *4200A-SCS Parameter Analyzer Datasheet* for more information on the PMU maximum source power versus device resistance. You can access the datasheet from the *Learning Center*.



For user test modules (UTMs), although the process described above applies, there are a few differences. Although ITMs and UTMs can perform similar tests, UTMs are based on user modules. UTMs have a much wider range of test behaviors and possibilities than ITMs. This document provides a framework for troubleshooting UTMs (individual UTM issues are not covered).

In addition to the above procedure based on unexpected results, UTM troubleshooting also involves error messages or codes. Typically, the user modules are written for a specific test or requirement and have minimal error checking. This means that parameter values or combinations of parameter settings may cause an error, which is the primary feedback about the test status.

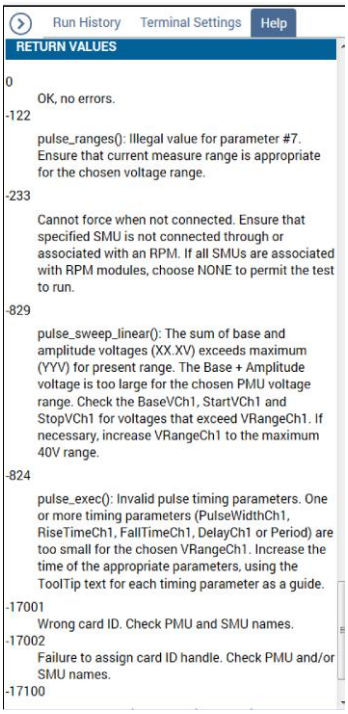
This error may be generated from within the user module, or by an LPT command. The following figure shows the user module description for `PMU_IV_sweep_Example`. This description is part of the user module and may contain a description of the test, hardware requirements, individual parameter descriptions, and error code listings. The error code listings are after the parameter descriptions, which are typically at the bottom of the description content (you will need to scroll down the Help pane).



This user module allows for an optional SMU to DC bias a transistor bulk while performing a pulse I-V sweep with a 4225-PMU and optional 4225-RPM. However, due to system restrictions, this SMU must not be connected to the test device through the 4225-RPM (an error results).

This example test is configured to use SMU1. SMU1 is connected through RPM1 of the system.

1. Set the SMU_ID from NONE to SMU1.
2. Select **Analyze** and view the Messages area at the bottom of the screen for error messages. For example, if you get a message indicating "forcev(): Cannot force when not connected," you can check the Return Values in the Help pane for more troubleshooting information, as shown in the following figure. Note that value `-233` indicates, "Ensure that the specified SMU is not connected through or associated with an RPM. If all SMUs are associated with RPM modules, choose NONE to permit the test to run."



NOTE

It may also be necessary to research further using additional error codes. Three-digit negative error codes are most likely LPT-command error codes. Refer to “LPT Library Status and Error codes“ in *Model 4200A-SCS LPT Library Programming*. One-digit, four-digit, or five-digit error numbers are most likely from the user module, so refer to the user module description for information about these type of errors.

Section 4

Pulse card concepts

Models 4220-PGU and 4225-PMU

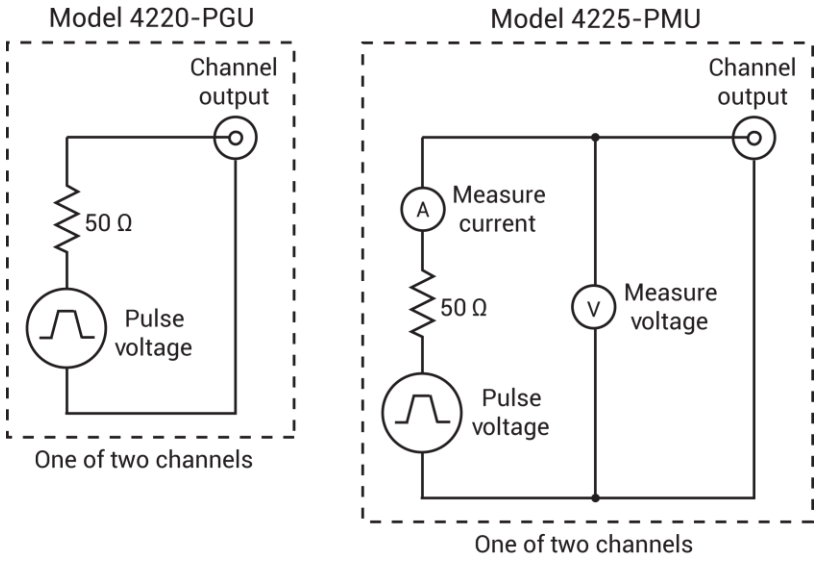
The 4220-PGU High Voltage Pulse Generator Unit and 4225-PMU Ultra-Fast Pulse Measure Unit are high-speed pulse-generator cards for the 4200A-SCS. The 4220-PGU provides pulse output only. The 4225-PMU provides both pulse output and pulse measurement. The PGU and PMU have similar pulse output characteristics.

The 4225-PMU can be paired with one or two 4225-RPM Remote Preamplifier/Switch Modules. The RPM is a remote amplifier and automatic switch. When the RPM is used as a preamplifier for the PMU, it provides additional low-current measurement ranges. When the RPM is used as a switch, it switches between the PMU, SMUs, and CVUs.

LPT functions that pertain to the PGU and PMU are documented in “LPT commands for PGUs and PMUs” in *Model 4200A-SCS LPT Library Programming*.

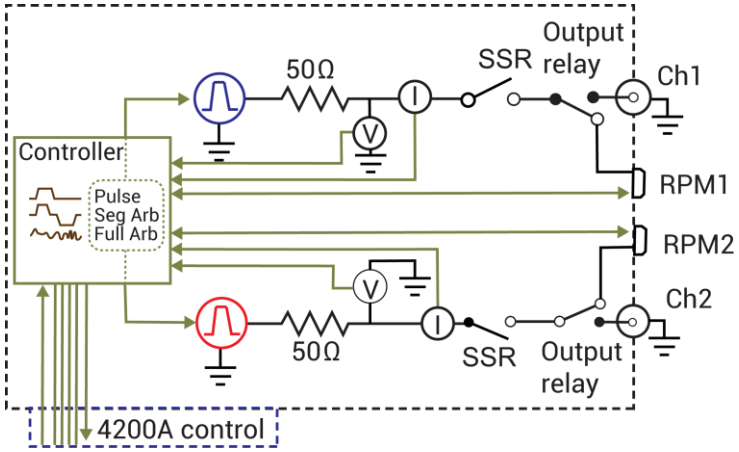
To do quick tests with minimal interaction with other 4200A-SCS test resources, you can use the Keithley Pulse Application (KPulse). KPulse is a nonprogramming alternative that you can use to configure and control the installed Keithley pulse cards. Refer to KPulse (on page 108) for additional information.

The simplified circuits of the 4220-PGU and 4225-PMU pulse generators are shown in the following figure.



PMU block diagram

The following figure shows the block diagram of the PMU. Each channel has two dedicated A/D converters to simultaneously measure current and voltage. The PMU controller controls the two output channels and any RPMs connected to it. The solid-state relays (SSRs) are high-speed and are used to test flash memory. The mechanical output relays are low-leakage. The block diagram for the PGU is similar, except it does not have measure capability and does not have the RPM connectors.



Pulse modes

The PGU and PMU support the following pulse modes:

- **Standard pulse mode:** For this two-level pulse mode, the user defines a high and low level for the pulse output. The test modes for standard pulse are pulse I-V and waveform capture. See PMU Test Settings (on page 47) for the standard (two-level) pulse mode. In Pulse mode, the minimum pulse width is 10 ns with no measurement and 60 ns when measuring.
- **Segment Arb™ waveform:** For this multi-level pulse mode, the user defines a pulse waveform that consists of three or more line segments. Segment Arb pulse mode for the PGU and PMU includes sequencing and sequence looping (see `seg_arb_sequence` and `seg_arb_waveform`. Also see Segment Arb waveform (on page 88) for details on parameters.
- **Full-arb pulse mode:** For this multilevel pulse mode, the waveform consists of a number of user-defined points (see `arb_array` and `arb_file`). Also see Full Arb waveform (on page 90) for details on parameters.

KPulse supports all of these pulse modes.

Descriptions of the LPT functions are provided in *Model 4200A-SCS LPT Library Programming*.

Pulse measurement types (PMU)

The following table summarizes pulse measurement types that are available through LPT commands for the 4225-PMU. See Measurement types (on page 100) for detailed information.

Pulse measurement types

Measurement type	Description
Spot mean discrete	Samples a portion of the high and low levels. The samples are averaged to yield a single current and voltage reading for the high level and low level (see the Spot mean measurements example figure; Measurement types (on page 100)).
Spot mean average	A specified number of pulse periods are output for the burst sequence. Spot mean discrete measurements are performed for each pulse and then averaged to yield a single voltage and current reading for the high and low levels.
Waveform discrete	The entire pulse is sampled. Sampling is performed on the rise time, top width, and fall time portions of the pulse. A voltage and current reading is yielded for every sample taken on the pulse (see Measurement types (on page 100) Waveform measurements and Waveform measurements (with pre-data and post-data) figures).
Waveform average	A specific number of pulses are output for the burst sequence. Waveform discrete measurements are performed on each pulse. The corresponding samples for each pulse are then averaged to yield a group of voltage and current readings for the burst sequence.

Measure modes

The measure modes for the PMU are discrete pulses and average pulses.

Discrete pulses

For pulse I-V (spot mean), the averaged voltage or current readings for every sampled pulse period are acquired.

For waveform capture, enabled voltage and current readings and timestamps for every sample of the waveform are acquired.

For ITM operation, the readings are placed in the Analyze sheet.

NOTE

See Spot mean discrete readings (on page 101) for details on the discrete pulses measure mode for pulse I-V. For UTM programming, the discrete pulse measure mode is called spot mean discrete. The `pulse_meas_sm` function is used to select the discrete acquisition type.

See Waveform discrete readings (on page 103) for details on the discrete pulses measure mode for waveform capture. For UTM programming, the discrete pulse measure mode is called waveform discrete. The `pulse_meas_wfm` function is used to select the discrete acquisition type.

Average pulses

For pulse I-V (spot mean), the mean values of two or more pulses are averaged. Think of it as the "mean of the means."

For waveform capture, each acquired reading is a mean average of the corresponding samples for all the pulses in the burst.

NOTE

See Spot mean average readings (on page 102) for details on the average pulses measure mode for pulse I-V. For UTM programming, the average pulse measure mode is called spot mean average. The `pulse_meas_sm` function is used to select the average acquisition type.

See Waveform average readings (on page 104) for details on the average pulses measure mode for waveform capture. For UTM programming, the average pulses measure mode is called waveform discrete. The `pulse_meas_wfm` function is used to select the average acquisition type.

4200A-SCS power supply limitations

In some system configurations, the 4200A-SCS power supply cannot supply enough current if a test has too many high-power instruments enabled. Some system configurations may have enough instruments installed to exceed the power supply limit if the selected test has too many channels enabled.

Clarius tracks the instruments used in a test and calculates the maximum power required and compares it to the maximum available power. If the test requires too much power, a message is displayed and the test will not run.

The following table and the equations below it show how the power is calculated. The maximum power available for each instrument in the test module is used in the calculation. The 4210-SMU High Power SMU, 4211-SMU High Power SMU, 4225-PMU Ultra-Fast Pulse Measure Unit, and 4220-PGU High Voltage Pulse Generator draw the majority of the power in the 4200A-SCS chassis.

There are two parts to the total power supply draw. The first part is the power required for the instruments while the 4200A-SCS is idle (on, but not testing). The second part is the power required by the instruments taking part in the test. Note that medium power SMUs (4200-SMUs and 4201-SMUs), 4200 preamplifiers (4200-PAs), and 4210-CVU and 4215-CVU modules are not included in the equations, as their power draw is not significant.

4200A-SCS power requirements

Instrument	Idle power (watts)	Test power (watts)
High Power SMU (4210-SMU or 4211-SMU)	Not significant	45
4225-PGU	29.4	Not available
4225-PMU	50.4	Not available
4225-RPM	4.2	Not available
10 V PGU or PMU channel*	Not available	8.4
40 V PGU or PMU channel*	Not available	54.6
Medium Power SMU (4200-SMU or 4201-SMU)	Not significant	Not significant
4210-CVU or 4215-CVU	Not significant	Not significant

* There are two channels for each PGU and PMU instrument card.

Equations to calculate power:

PowerIDLE = [(29.4 × *nPGU*) + (50.4 × *nPMU*) + (4.2 × *nRPM*)]

PowerTEST = [(45 × *nHPSMU*) + (8.4 × *nC10*) + (54.6 x *nC40*)]

PowerTOTAL = PowerIDLE + PowerTEST

PowerTOTAL = 500 W maximum. If PowerTOTAL is less than or equal to 500 W, the test proceeds.

Where:

- *nPGU* = number of 4220-PGU cards in the 4200A-SCS chassis (idle power draw)
- *nPMU* = number of 4225-PMU cards in the 4200A-SCS chassis (idle power draw)
- *nRPM* = number of 4225-RPM modules connected to PMUs (idle power draw)
- *nHPSMU* = number of High-Power SMUs (4210-SMUs or 4211-SMUs) in the test
- *nC10* = number of 10 V PGU or PMU channels in the test
- *nC40* = number of 40 V PGU or PMU channels in the test

Example 1: 4200A-SCS with two 4210-SMUs or 4211-SMUs, four 4225-PMUs, and eight 4225-RPMs. The test uses all eight PMU+RPM channels set to the 10 V range (no SMUs in test).

PowerIDLE = [(29.4 × *nPGU*) + (50.4 × *nPMU*) + (4.2 × *nRPM*)] = [(29.4 × 0) + (50.4 × 4) + (4.2 × 8)] = 201.6 + 33.6 = 235.2

PowerTEST = [(45 × *nHPSMU*) + (8.4 × *nC10*) + (54.6 × *nC40*)] = [(45 × 0) + (8.4 × 8) + (54.6 × 0)] = 67.2

PowerTOTAL = PowerIDLE + PowerTEST = 235.2 + 67.2 = 302.4

This test has PowerTOTAL ≤500 W, so this test will proceed.

Example 2: 4200A-SCS with two 4210-SMUs or 4211-SMUs, four 4225-PMUs, and eight 4225-RPMs. The test uses five PMU+RPM channels set to the 40 V range (no SMUs in test).

PowerIDLE = [(29.4 × *nPGU*) + (50.4 × *nPMU*) + (4.2 × *nRPM*)] = [(29.4 × 0) + (50.4 × 4) + (4.2 × 8)] = 201.6 + 33.6 = 235.2

PowerTEST = [(45 × *nHPSMU*) + (8.4 × *nC10*) + (54.6 × *nC40*)] = [(45 × 0) + (8.4 × 0) + (54.6 × 5)] = 273

PowerTOTAL = PowerIDLE + PowerTEST = 235.2 + 273 = 508.2

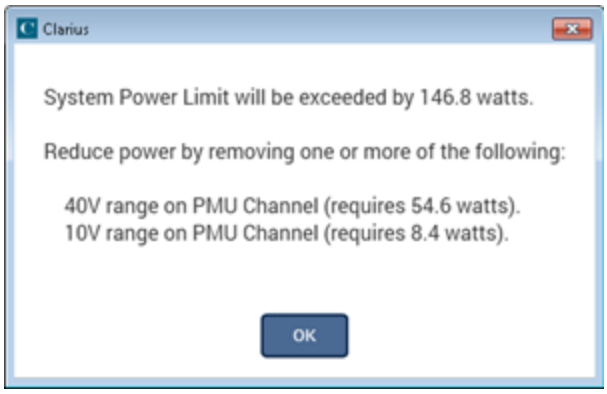
This test has PowerTOTAL >500 W, so this test will not proceed. Reduce the number of PMU+RPM channels that are set to the 40 V range to less than five.

The following table shows the 4200A-SCS power requirements for valid combinations for the 4225-PMU, 4225-RPM, and high-power SMU.

4200A-SCS power requirements for valid combinations of internal system instruments

Idle power (watts)		**Power used in test (watts)**					
nPMU	***nRPM***	***nC10***	***nC40***	***nHPSMU***	**PowerIDLE**	**PowerTEST**	**PowerTOTAL**
2	4	0	4	0	117.6	218.4	336
2	4	0	4	1	117.6	263.4	381
2	4	0	4	2	117.6	308.4	426
2	4	4	0	2	117.6	123.6	241.2
3	6	6	0	0	176.4	50.4	226.8
3	6	6	0	1	176.4	95.4	271.8
3	6	6	0	2	176.4	140.4	316.8
3	6	0	5	0	176.4	273	449.4
3	6	0	5	1	176.4	318	494.4
4	8	8	0	0	235.2	67.2	302.4
4	8	8	0	1	235.2	112.2	347.4
4	8	8	0	2	235.2	157.2	392.4
4	8	0	4	0	235.2	218.4	453.6
4	8	0	4	1	235.2	263.4	498.6
5	10	10	0	0	294	84	378
5	10	10	0	1	294	129	423
5	10	10	0	2	294	174	468
5	10	0	3	0	294	163.8	457.8
5	10	0	2	1	294	154.2	448.2
5	10	0	2	2	294	199.2	493.2
6	12	12	0	0	352.8	218.4	336
6	12	12	0	1	352.8	263.4	381
6	12	0	2	0	352.8	308.4	426
6	12	0	1	1	352.8	123.6	241.2

The power limit check is performed in both ITMs and UTMs. In ITMs, exceeding the power limit will display a message similar to the one shown in the following figure when configuring PMU.



For UTMs, the message appears in the Clarius Messages pane.

Pulse source-measure concepts

Ultra-fast I-V sourcing and measurement have become increasingly important capabilities for many technologies, including compound semiconductors, medium-power devices, nonvolatile memory, microelectromechanical systems (MEMs), nanodevices, solar cells, and CMOS devices. Using pulse I-V signals to characterize devices rather than DC signals makes it possible to study or reduce the effects of self-heating (joule heating) or to minimize current drift or degradation in measurements due to trapped charge. Transient I-V measurements allow scientists and engineers to capture ultra high-speed current or voltage waveforms in the time domain or to study dynamic test circuits. Pulsed sourcing can be used to stress test a device using an AC signal during reliability cycling or in a multi-level waveform mode to program or erase memory devices. The 4225-PMU Ultra-Fast I-V Module for the 4200A-SCS supports many of these high-speed sourcing and measurement applications.

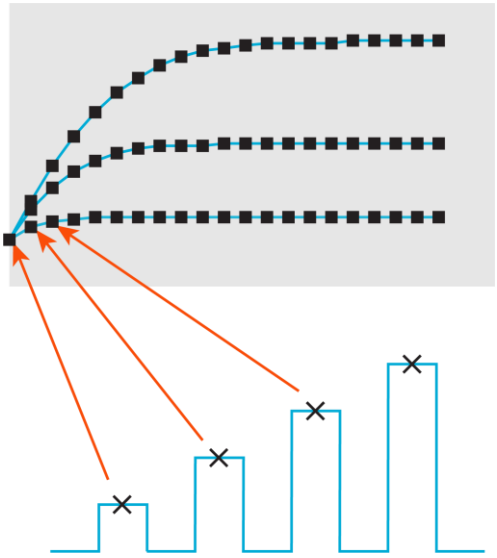
Ultra-fast I-V tests

You can use the 4225-PMU to do these types of ultra-fast I-V tests:

- Pulse I-V
- Transient I-V
- Pulsed sourcing

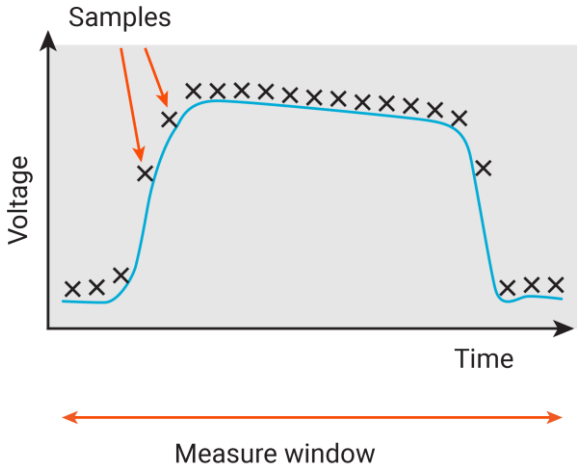
Pulse I-V tests

Pulse I-V tests are tests with a pulsed source and a corresponding high speed, timed-based measurement that provides DC-like results. The current plus voltage measurement is an average of readings made in a predefined measurement window on the pulse. This average of readings is called the spot mean. You can define the parameters of the pulse, including the pulse width, duty cycle, rise and fall times, and amplitude. You can use the train, sweep, or step mode.



Transient I-V tests

Transient I-V, or waveform capture, is a time-based current or voltage measurement that is typically the capture of a pulsed waveform. A transient test is typically a single pulse waveform that is used to study time-varying parameters, such as the drain current degradation versus time due to charge trapping or self-heating. Transient I-V measurements can be made to test a dynamic test circuit or can be used as a diagnostic tool for choosing the appropriate pulse settings in the pulse I-V mode.

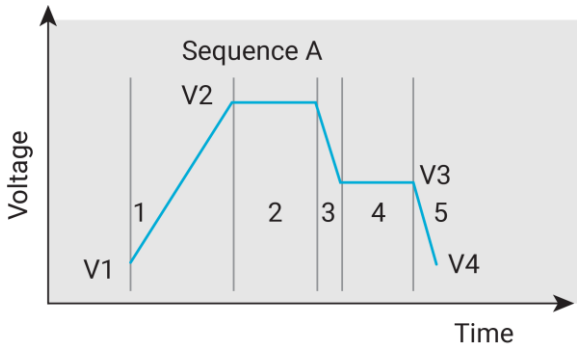


Pulsed sourcing tests

Pulsed sourcing can involve any of the following:

- Outputting user-defined two-level pulses.
- Outputting multi-level pulses using the built-in Segment Arb™ function.
- Outputting an arbitrarily defined waveform using the arbitrary waveform generator in the KPulse software. The Segment Arb feature allows you to create waveforms from segments defined with separate voltages and time durations.

In addition to its pulse generator capabilities, the 4225-PMU can measure AC or DC voltage and current, thereby reducing the need for additional measurement hardware and more complicated programming. The 4220-PGU is a two-channel pulse generator with output capabilities identical to the capabilities of the 4225-PMU, but without its measurement functions.



Sequence A definition

Segment	Start V	Stop V	Duration
1	V1	V2	T1
2	V2	V2	T2
3	V2	V3	T3
4	V3	V3	T4
5	V3	V4	T5

Sample rate

For the PMU, the maximum measurement sampling rate for each A/D test is 200e6 (200 million) samples per second. However, there is a limit to the number of samples (one million) that can be acquired per A/D test. When a test is configured to exceed that limit, the sample rate is automatically lowered when using ITMs so that fewer than one million samples are acquired.

Waveform

A Clarius ITM can accept up to 4096 data points and a UTM can accept up to 65,536 data points. This means the sampling rate should be reduced to produce a smaller number of data points than the maximum acceptable limit for the test.

If Clarius reaches the low limit for the sample rate (when even slowest sample rate produces more than the accepted number of data points), you see an error such as “The specified pulse settings produce over 4096 data points. Reduce the number of pulses or increase the pulse timing parameters.” A test with these conditions cannot be executed.

Pulse I-V (spot mean)

The maximum number of samples per A/D per test is <1,000,000 (one million). If an ITM is configured to yield more than one million samples, Clarius automatically lowers the sampling rate. For pulse I-V (spot mean), typically the sample rate is reduced only if the measure window is wide (due to a wide pulse width or period) or if the number of pulses is large.

The total number of samples for a test is calculated as follows:

Number of samples = Measure window x Sample rate × Number of pulses × Sweep points × Step points

Example: Test that uses a single PMU to perform 50 20-step sweeps

Pulse width = approximately 7 µs

Measure window = 1 µs

Sample rate = 200e6 samples per second

Number of pulses = 50

Number of steps in sweep = 20

The number of samples acquired for the above example is calculated as follows:

Number of samples = 1 µs x 200e6 x 50 x 20 = 200,000

Because the number of samples is less than the one million sample limit, the sample rate of 200e6 samples per second is used for the above example.

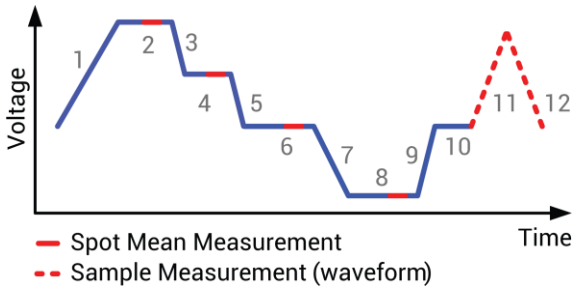
Segment Arb waveform

The Segment Arb™ feature in Clarius is an arbitrary waveform generator that you can use with the PGU and PMU pulse cards. It can provide multi-sequence, multi-segment pulse waveforms with 10 ns programmable resolution. You can configure each pulse channel to output a unique Segment Arb waveform.

For PMUs, you can also use Segment Arb waveforms for spot mean and sample measurements. Spot mean measurements take a mean of all the samples within the measured window and result in a single reading for that segment. Sample measurements report all of the samples within the measurement window, which can then be plotted versus time to produce a waveform capture.

Each Segment Arb waveform is based on sequences of segments, with up to 512 sequences. Each sequence may have from 3 to 2048 segments. The total number of segments in a Segment Arb waveform is also limited to 2048. For example, a Segment Arb waveform can have one sequence with 2048 segments in it. You could also have two sequences, each of which contains 1024 segments.

To set up a Segment Arb waveform, you specify a list of segments. For each segment, you can define unique time intervals, voltage start and stop values, measure times and types, output trigger levels, and output relay states. The waveform sequences can be configured in list of sequences with a loop count property for each sequence. The pulse card outputs waveform sequences in the order defined in the list, while looping each sequence the number of times defined by the loop count. An example of the line segments is shown in the following figure. The blue line represents the voltage waveform. The red line represents the measure windows. This figure contains a 12-segment waveform.



NOTE

If both channels of a pulse card are used, the segment trigger levels for Channel 1 are at the TRIGGER OUT connector. The trigger levels for Channel 2 are ignored.

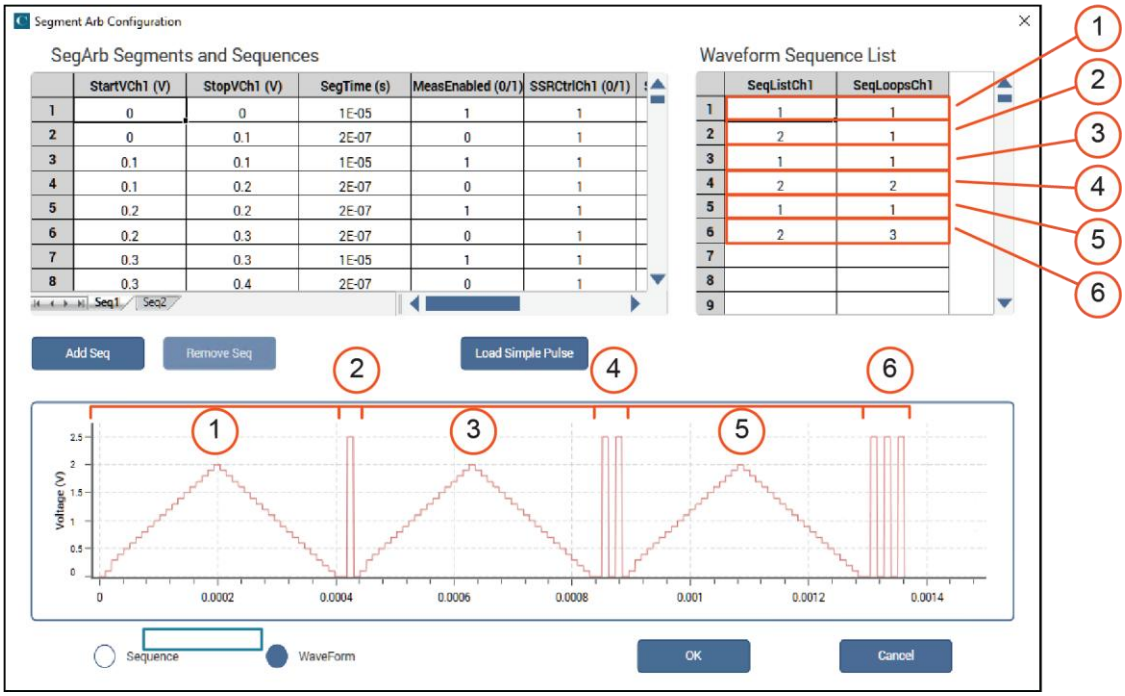
NOTE

The PMU minimum segment width when measuring is 20 ns. For pulse only, the minimum width is 10 ns. For pulse-only waveforms below 20 ns, refer to *Technical Note: Generating 10ns Pulse Widths Using the 4225-PMU*.

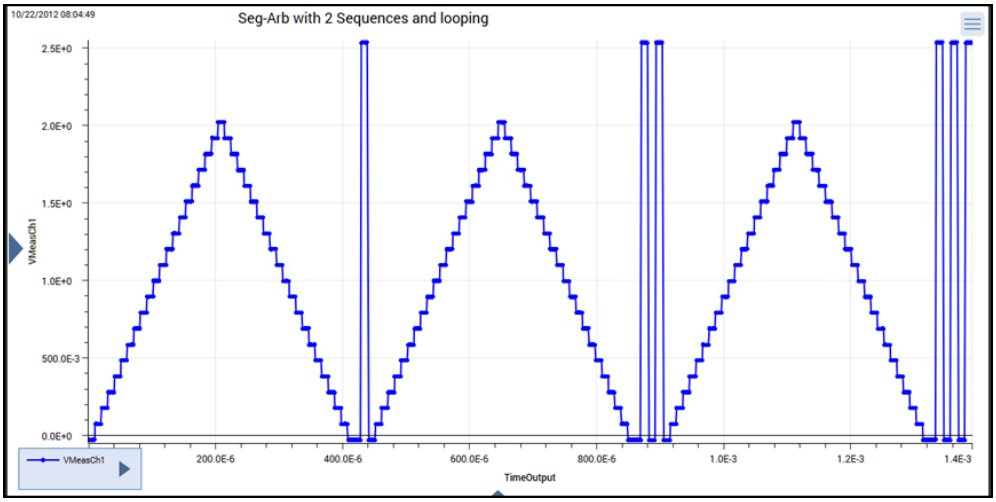
Each output channel of a pulse card has a high-speed, solid-state output relay. When this relay is closed, the waveform segment is output. When opened, the channel output is electrically isolated (floating) from the DUT. The minimum time for a segment with a relay transition (open-to-close or close-to-open) is 25 µs.

Waveforms are set up and run using UTMs. The Clarius project `pmu-dut-examples` includes several preconfigured tests that are based on user modules in the user library `PMU_examples_ulib`. You can also create custom UTMs using the LPT commands `seg_arb_define`, `seg_arb_sequence`, and `seg_arb_waveform`. To set up and run waveforms from a remote computer, you can use the KXCI `:PMU:SARB:*` set of commands.

An example of the `pmu-segarb-complete` test, which has two sequences with looping, is illustrated in the following figure.



The `pmu-segarb-complete` test produces the Analyze graph shown in the following figure.



Full arb waveform

You can configure each channel of the pulse generator to generate its own unique full arb waveform. A full arb waveform is made up of user-defined points (up to 262,144).

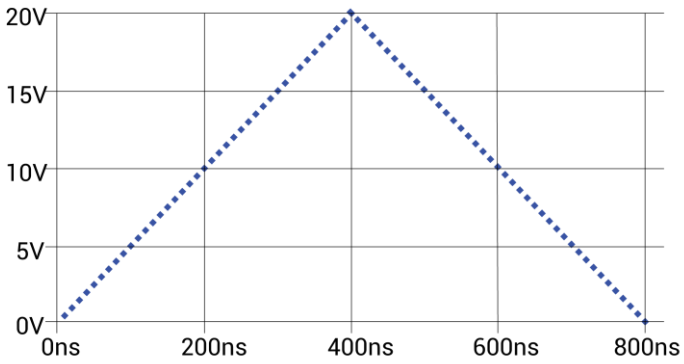
Each waveform point can have its own unique voltage value. A time interval is set to control the time spent at each point in the waveform. The following figure shows an example of a user-defined full arb waveform. The waveform is made up of 80 voltage points, with the time interval between each point set to 10 ns.

Use the `arb_array` function to define a full arb waveform. This function includes parameters to specify the number of waveform points, the time interval, an array of voltage levels, and a file name. For more information, refer to `arb_array`.

The `arb_file` function is used to load the defined full arb waveform into the pulse generator. For more information, refer to `arb_file`.

The following voltage level array is required for the full-arb waveform shown in this graph.

Level array	Level array (continued)
levelArr[0] = 0.5	levelArr[41] = 19.5
levelArr[1] = 1.0	levelArr[42] = 19.0
levelArr[2] = 1.5	levelArr[43] = 18.5
•	•
•	•
•	•
levelArr[39] = 19.5	levelArr[79] = 0.5



KPulse full arb waveforms

The Keithley Pulse tool (KPulse) is a software application used to control the optional pulse generator cards. KPulse can be used to create, save, and output full arb waveforms. It also provides a collection of basic full arb waveform types such as sine, square, triangle, noise, Gaussian, and calculation. After configuring one of the basic waveform types, you can save it as a `.kaf` file.

Once a full arb waveform is saved as a `.kaf` file, it can be imported back into KPulse. The waveform can also be loaded into the pulse generator card using the `arb_file` function. For more information, refer to KPulse (on page 108).

Pulse waveforms for nonvolatile memory testing

The pulse card has several attributes that support nonvolatile memory (NVM) testing.

To perform the multi-level pulse waveforms for the typical program/erase waveform, each pulse card channel uses the Segment Arb mode. For more information about Segment Arb waveforms, refer to Segment Arb waveforms (on page 112). The ability to disconnect, or float, a particular device pin in the Segment Arb waveform requires an inline solid-state relay.

The pulse card output channels each have 50 Ω output impedance for most ranges. When current flows through the pulse channel, there is a voltage drop across this 50 Ω resistor internal to the pulse card. This dictates that the voltage at the output may be different from what is expected based on the resistance of the DUT. This effect is called the load-line effect. For more information on the load-line effect and how to compensate for it, refer to Load-line effect compensation (LLEC) for the PMU (on page 23).

The DUT resistance determines pulse voltage across DUT:

- The gate of a flash or NVM device has high impedance.
- The voltage at the gate is double of the programmed voltage.
- The voltage at the drain is a function of the resistance of the drain-source, as mentioned above.

Adjusting the pulse level to match the expected drain voltage is performed iteratively with an oscilloscope to measure V_D during the pulse.

The methods used to define the multi-level waveforms used in flash memory testing include using the subsite stress/measure looping feature of Clarius. Use the KPulse application to define each unique voltage waveform. Refer to KPulse (on page 108) for details.

Waveform capture number of samples

The maximum number of rows that can appear in the Analyze sheet for an ITM is 4096. Each waveform sample uses one row of the sheet. Therefore, the number of samples acquired for a waveform must fit within the 4096 points.

The number of samples (rows) for a waveform that is 20.48 µs wide is calculated as follows:

Number of samples (rows) = Sample rate × waveform width

= 200e6 × 20.48 µs

= 4096

If the waveform is any wider, the sample rate is automatically lowered by Clarius to fit the waveform within the 4096 points.

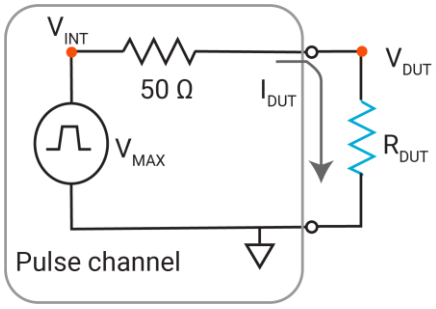
Waveform width that is sampled includes pulse rise, pulse magnitude, pulse fall, and a small portion of the base level before the rise and after the fall.

DUT resistance determines pulse voltage across DUT

Each output channel of the 4220-PGU pulse card is effectively a voltage source with a series 50 Ω resistance. While PMUs have measurement capability, the 4220-PGU pulse card does not, so the actual voltage across the device under test (DUT) is directly related to the DUT resistance.

There are many output effects that are part of using a pulse generator. This section covers the most common issue, which is the voltage across the DUT not meeting initial expectations.

There is more than one way to explain the effect of impedance on the DUT voltage. The approach used below relies on DC concepts and explains the settled portion of the pulse and does not require knowledge or use of RF concepts. RF concepts are necessary to explain time-based effects, such as rise time, overshoot, ringing, and reflection.



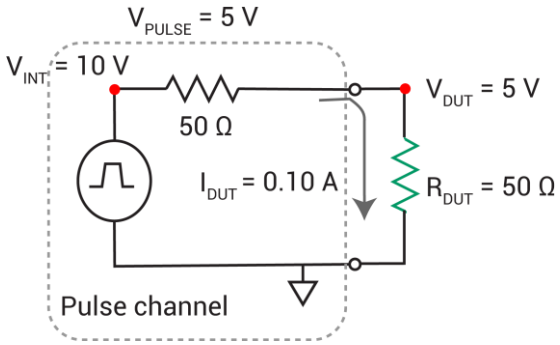
As shown in the figure, the voltage across the DUT, V_{DUT}, is directly related to the resistance R_{DUT}. The discussion here is simplified, including resistive impedances only.

The 50 Ω output resistance of the pulse channel and the DUT resistance effectively make a voltage divider. Ohm's law is the only concept required to determine I_{DUT} and V_{DUT} in this simple nondynamic approach. Calculate the current, and then use the current to calculate the voltage across the DUT.

Example 1: Ideal situation (50 Ω DUT)

The ideal situation (50 Ω DUT) is shown in the following figure.

R_{DUT}	50 Ω
Pulse V_{HIGH}	5 V
Pulse V_{LOW}	0 V
Pulse load	50 Ω



Example 1, showing a 5 V pulse into a 50 Ω DUT load.

V = I × R (Ohm's Law)

Calculate the current, I_{DUT}:

$I_{DUT} = V_{TOTAL}/R_{TOTAL} = V_{INT}/ (50\ \Omega + 50\ \Omega) = 10\ V / 100\ \Omega = 0.1\ A$

Note that the internal voltage, V_{INT}, is 2 times the requested 5 V, so that V_{DUT} = 5 V. The 2 times multiplier is the default case, where:

R_{DUT} = Pulse Load = 50 Ω

Pulse load is a channel-based parameter that allows the pulse generator to calculate the value of the multiplier to source the proper voltage to provide the desired pulse level for the supplied value of the pulse load. Whenever the value for pulse load does not equal the actual DUT resistance, the voltage across the DUT will not match the programmed voltage level.

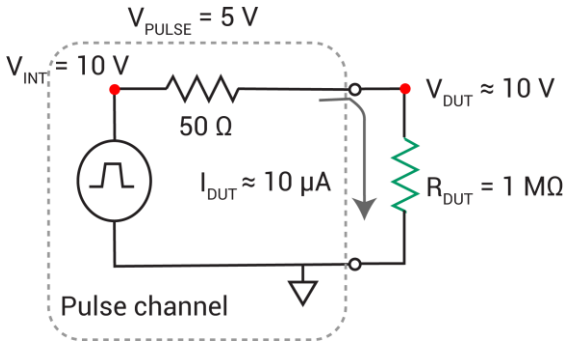
Calculate V_{DUT}:

$V_{DUT} = I_{DUT} \times R_{DUT} = 0.1\ A \times 50\ \Omega = 5\ V$.

Example 2: High resistance DUT

A high resistance DUT is shown in the following figure.

R_{DUT}	1 MΩ
Pulse V_{high}	5 V
Pulse V_{low}	0 V
Pulse load	50 Ω



This example shows a 5 V pulse into a 1 MΩ DUT load.

Calculate the current, I_{DUT}:

$I_{DUT} = V_{TOTAL}/R_{TOTAL} = V_{INT}/ (50\ \Omega + 1\ M\Omega) = 10\ V / 1.00005E+6\ \Omega = 9.9995E-6\ A \approx 10\ \mu A$.

Calculate V_{DUT}:

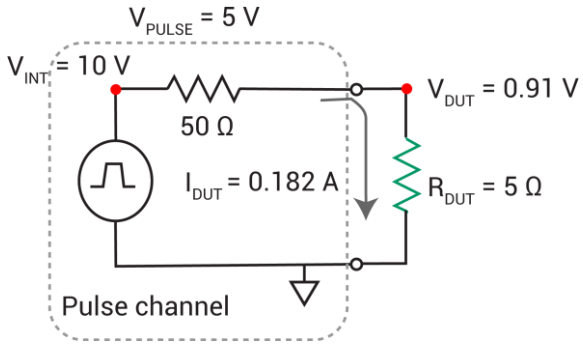
$V_{DUT} = I_{DUT} * R_{DUT} = 10\ \mu A * 1E6\ \Omega \approx 10\ V$.

$V_{DUT} \approx 10$ V because the pulse load = 50 Ω, but R_{DUT} = 1 MΩ. The pulse generator calculates the output voltage based on the pulse load, and uses a 2 times multiplier to determine V_{INT} = 10 V. Since the pulse generator cannot measure the output voltage or DUT load, this example results in a V_{DUT} that is 2 times the programmed level.

Example 3: Low resistance DUT

A low resistance DUT is shown in the following figure.

R_{DUT}	5 Ω
Pulse V_{HIGH}	5 V
Pulse V_{LOW}	0 V
Pulse load	50 Ω



This figure shows a 5 V pulse into a 5 Ω DUT load.

Calculate the current, I_{DUT}:

$I_{DUT} = V_{TOTAL}/R_{TOTAL} = V_{INT}/ (50\ \Omega + 5\ \Omega) = 10\ V / 55\ \Omega = 0.182\ A$

Calculate V_{DUT}:

$V_{DUT} = I_{DUT} * R_{DUT} = 0.182\ A * 1E6\ \Omega = 0.91\ V$

All pulse parameters were constant across all three examples. Only the DUT load (R_{DUT}) was changed, resulting in a range of V_{DUT} from less than 1 V to nearly 10 V, with corresponding changes in I_{DUT}. This variation is related to the constant pulse load = 50 Ω. Reprogramming the pulse load value to match R_{DUT} would prevent this behavior, but is not practical in many situations.

This effect is inherent to the pulse generator and DUT system. The general approach for calculating the current and voltage is given in the examples above. Calculating the maximum voltage and current available for any given DUT resistance is similar to the above examples. The only difference is that the maximum voltage available is used for the range. For the high-speed range, V_{MAX} = 10 V, for the high voltage range, V_{MAX} = 40 V.

Example 4: Maximum voltage and current, high speed range

$V = I * R$

V_{MAX} = 10 V for high speed range

R_{DUT} = 5 Ω

$I_{MAX} = V_{MAX} / R_{TOTAL} = V_{MAX} / (R_{pulse\ generator} + R_{DUT})$

I_{MAXDUT} = 10 V / (50 Ω + 5 Ω) = 10 V / 55 Ω = 0.182 A

$V_{MAXDUT} = I_{MAX} * R_{DUT}$ = 0.182 A * 5 Ω = 0.91 V

These I_{MAX} and V_{MAX} values match the values in the Pulse Card High Voltage (5 V) Range table for the 5 Ω row (see following table). These calculations do not incorporate any cabling or interconnect losses that may range from 1 Ω up to 10 to 20 Ω, depending on the interconnect method and DUT type (packaged or on-wafer).

Example 5: Maximum voltage and current, high voltage range

$V = I * R$

V_{MAX} = 40 V for High Voltage Range

R_{DUT} = 250 Ω

$I_{MAX} = V_{MAX} / / R_{TOTAL} = V_{MAX} / (R_{pulse\ generator} + R_{DUT})$

I_{MAXDUT} = 40 V / (50 Ω + 250 Ω) = 40 V / 300 Ω = 0.133 A

$V_{MAXDUT} = I_{MAX} * R_{DUT}$ = 0.133 A * 250 Ω = 33.3 V

These I_{MAX} and V_{MAX} values match the values in the Pulse Card High Voltage (20 V) Range table for the 250 Ω row. These calculations do not incorporate any cabling or interconnect losses that may range from 1 Ω up to 10 to 20 Ω, depending on the interconnect method and DUT type (packaged or on-wafer).

The tables below show the maximum current and voltage for various R_{DUT} values for the two output ranges available on each pulse card channel. Note the calculated current and voltage values do not include any cabling or interconnect losses that reduce both the maximum available V_{DUT} and I_{DUT}.

Because V_{DUT} is a function of the load applied to the pulse card channel, this effect is sometimes called the load-line effect. There are several ways of working with this effect. The simplest one is to program the DUT load into the pulse card channel using the LPT function `pulse_load`, or setting the Pulse Load value in the KPulse (on page 108) virtual front panel. The pulse card will calculate the appropriate V_{INT} to output so that the V_{DUT} pulse waveform, specified by `pulse_vlow` and `pulse_vhigh`, has the correct levels. For details, see Coping with the load-line effect (on page 27).

Test device resistance (Ω)	Voltage (V)*	Current (A)*
1	0.196	0.196
5	0.909	0.182
10	1.667	0.167
25	3.333	0.133
50	5	0.100
100	6.667	0.067
250	8.333	0.033
1 k	9.524	0.0095
10 k	9.950	0.000995

* Approximate value; does not account for interconnect losses.

Available I and V for the high voltage (20 V) range of the Keithley pulse card **Maximum I and V versus resistance**		
Test device resistance (Ω)	**Voltage (V)***	**Current (A)***
1	0.784	0.784
5	3.636	0.727
10	6.667	0.667
25	13.333	0.533
50	20	0.400
100	26.667	0.267
250	33.333	0.133
1 k	38.095	0.038
10 k	39.801	0.00398

*Approximate value; does not account for interconnect losses.

Triggering

Triggering is used for the following operations:

- Basic triggering (on page 98): Configure the Keithley pulse card for the trigger mode (Continuous, Burst or Trig Burst) and use a software trigger to start pulse output.
- Pulse-measure synchronization (on page 99): Synchronize the pulse-measure operation of a pulse generator card.

For each pulse in a test, a trigger pulse is sent to the trigger output. If you are using Segment Arb waveforms, you can define if a trigger out is sent for each segment.

The 4220-PMU and 4225-PGU are trigger out only (no trigger in). These pulse cards use the internal trigger bus for output synchronization when using any commands that require the `pulse_exec` function to execute.

If you need to define a trigger in using a source-only pulse waveform (2-level or Segment Arb), you can create a user test module (UTM) that uses the pulse source only (PG2) command set. This allows an external trigger (LPT command `pulse_trig_source`) to output a 2-level pulse (LPT commands `pulse_vhigh` and `pulse_vlow`) or segment arb waveforms (LPT command `seg_arb_define`). This allows for external triggering (a trigger input into the card) that causes a burst of pulses to be output.

Details on the trigger functions are provided in *Model 4200A-SCS LPT Library Programming*.

NOTE

Triggering transition time must be <100 ns. Trigger output Level and Trigger In Level must be TTL.

Basic triggering

The pulse output of a pulse card can be started by a software trigger. The LPT function for the software trigger also sets the trigger mode. Enabled pulse generator channels will then output a continuous string of pulses (continuous trigger mode), or a burst of pulses (burst or trig burst trigger mode).

Software trigger source

To use a software trigger to start pulse output, the software trigger source must first be selected. The `pulse_trig_source` function is used to select the software trigger source.

Trigger mode

With the software trigger source selected, using the `pulse_trig` function selects one of the following trigger modes and initiates (triggers) the start of pulse output:

- **Continuous:** This trigger mode continuously outputs pulses when pulse output is started.
- **Burst or Trig Burst:** These trigger modes output a burst of pulses when pulse output is started. A burst is a finite number of pulses (1 to $2^{32}-1$). The only difference between burst and trig burst is the behavior of trigger output (refer to Pulse generator card output trigger (on page 99)).

NOTE

When using the burst or trig burst trigger mode, make sure to first set the pulse count before starting pulse output. The `pulse_burst_count` function is used to set the burst count.

Example LPT function sequence: Basic triggering

The following LPT function sequence uses the software trigger to initiate a 3-pulse burst for both channels, where both the pulse and trigger output three pulses.

```
// Stop pulse generator output:
pulse_halt(VPU1);
// Select software trigger source:
pulse_trig_source(VPU1, 0);
// Set channel 1 for a burst count of 3:
pulse_burst_count(VPU1, 1, 3);
// Turn channel 1 on:
pulse_output(VPU1, 1, 1);
// Select the trigger burst mode and trigger start of burst output:
pulse_trig(VPU1, 2);
```

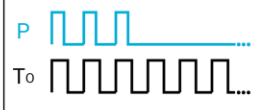
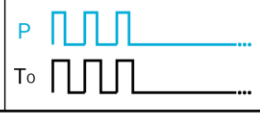
Pulse-measure synchronization

Synchronize the pulse-measure operation of a pulse generator card.

Pulse generator card output trigger

When output trigger is enabled, an output pulse will initiate a TTL-level, 50% duty cycle output trigger pulse. The trigger pulses are available at the TRIGGER OUT connector of the pulse generator card.

The following figure shows the behavior of output triggers (T_O) for the three trigger modes. Notice that for the Burst mode, output triggers continue even though pulse output has stopped. For the trigger burst mode, output triggers stop when the pulse output stops.

Trigger Mode	Standard Pulse	Full Arb Pulse	Segment Arb Pulse*
Continuous			
Burst			
Trig Burst			

P = Pulse output
T_O = Trigger output

*Segment Arb has user-defined trigger output (0 or 1) for each segment.

The `pulse_trig_output` function is used to enable or disable output trigger. Output trigger can be set for positive (rising edge) or negative (falling edge) polarity. Use the `pulse_trig_polarity` function to set the polarity of output trigger.

Example LPT function sequence: pulse-measure synchronization

The following LPT function sequence uses the software trigger to initiate a 3-pulse burst for CHANNEL 1. The three output pulses trigger the scope to perform three measurements. It assumes the scope is configured to trigger on leading edge triggers from the pulse generator.

```
// Stop pulse generator output:
pulse_halt(VPU1);
// Turn off trigger output:
pulse_trig_output(VPU1, 0);
// Set the output trigger polarity to positive:
pulse_trig_polarity(VPU1, 1);
// Select Software trigger source:
pulse_trig_source(VPU1, 0);
// Set channel 1 for a burst count of 3:
pulse_burst_count(VPU1, 1, 3);
// Turn channel 1 on:
pulse_output(VPU1, 1, 1);
// Select the Trig Burst trigger mode and trigger start of burst output. Each pulse
   will trigger the
// scope to perform a measurement.
pulse_trig(VPU1, 2);
```

Measurement types

There are two types of pulse measurements: Spot mean and waveform. The `pulse_meas_sm` function is used to configure Spot mean measurements (on page 101) and the `pulse_meas_wfm` function is used to configure Waveform measurements (on page 102).

The Model 4225-PMU makes the following types of pulse measurements:

- Spot mean discrete
- Spot mean average
- Waveform discrete
- Waveform average

Use the following pulse generator functions to configure pulse measurements:

- Use the `pulse_meas_sm` function to configure spot mean measurements; select the data acquisition type, set the readings to be returned, enable or disable timestamps, and set LLEC. See Spot mean measurements (on page 101) for details.
- Use the `pulse_meas_wfm` function to configure waveform measurements; select the data acquisition type, set the readings to be returned, enable or disable timestamps, and set LLEC. See Waveform measurements (on page 102) for details.
- Use the `pulse_meas_timing` function to set measurement timing. For spot mean measurements, portions of the amplitude and base levels are specified for sampling. For pre-data and post-data waveform measurements, a percentage of the entire pulse duration is specified. See Measurement timing (on page 104) for details on pulse measurement timing.

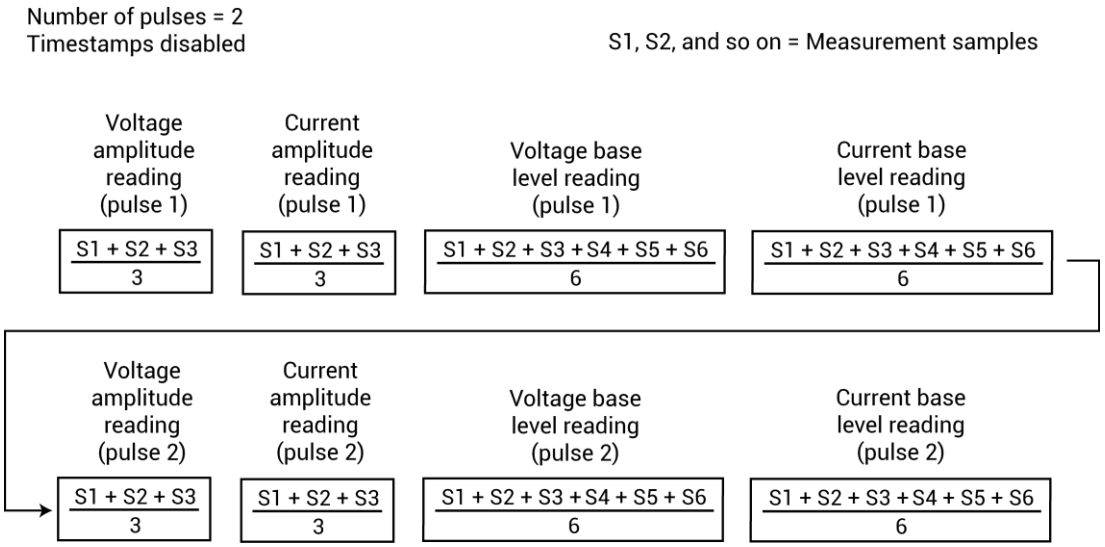
Spot mean measurements

Spot mean measurements sample a portion of the amplitude and a portion of the base level (see Spot mean measurement timing (on page 104)). The portions to be sampled are specified as a percentage. Note that you can return an individual spot mean for each pulse (see Spot mean discrete readings (on page 101)), or have a single spot mean for all *NumPulses* (see Spot mean average readings (on page 102)).

If you enable both amplitude and base spot means, each pulse has two voltage measurements and two current measurements (see `pulse_fetch`).

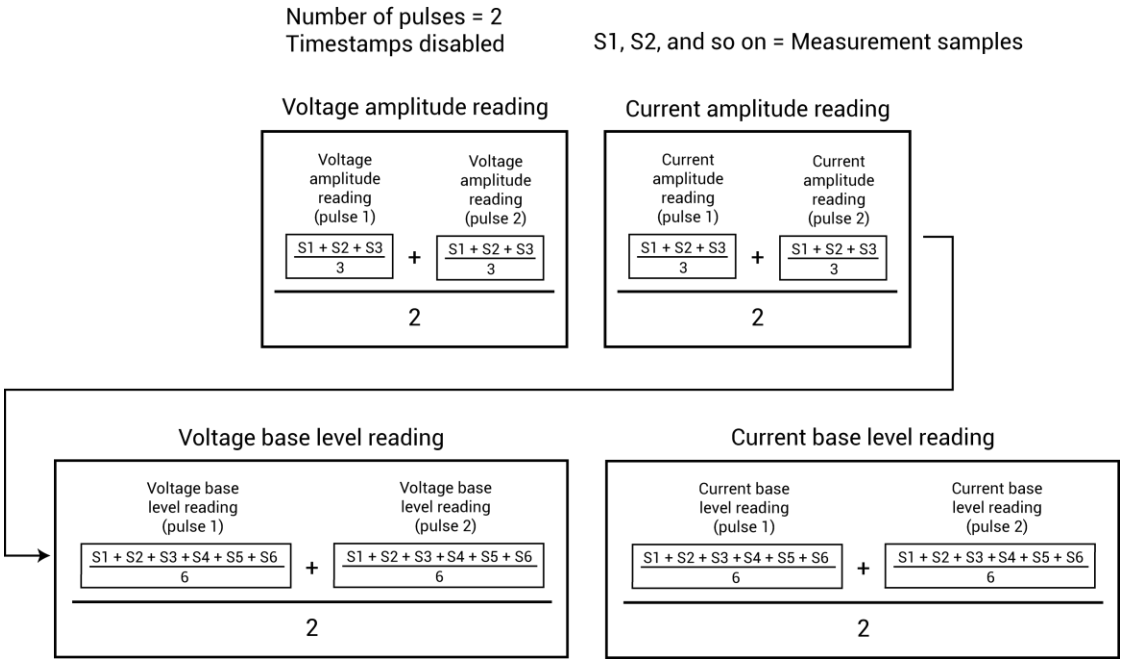
Spot mean discrete readings

The averaged voltage and current readings for every sampled pulse period are returned in a single data set. The following figure shows how spot mean discrete readings are returned as a data set for two pulse periods. With all voltage and current readings enabled, four readings are returned for each pulse. The measured samples are averaged to yield the mean average readings. When timestamps are enabled, a timestamp is included in the data set after each mean reading.



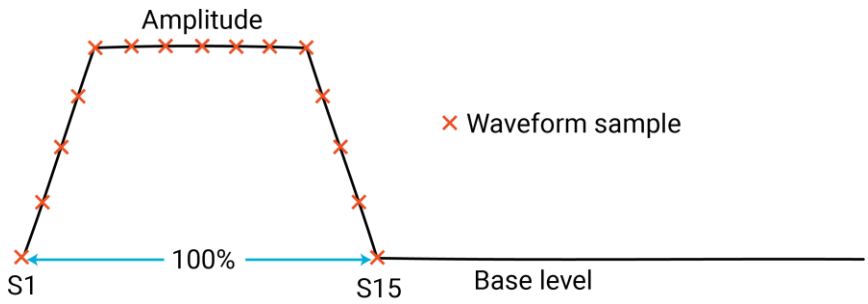
Spot mean average readings

For this data acquisition type, each returned reading is a mean-of-the-means. Spot mean average averages the mean readings for all the pulses in the burst. In the figure in Spot mean discrete readings (on page 101), each mean reading for pulse 1 is averaged with each corresponding mean reading for pulse 2 to yield the mean-of-the-means readings shown below. With all voltage and current readings enabled, four readings are returned for the burst. When timestamps are enabled, a timestamp is included in the data set after each mean-of-the-means reading.

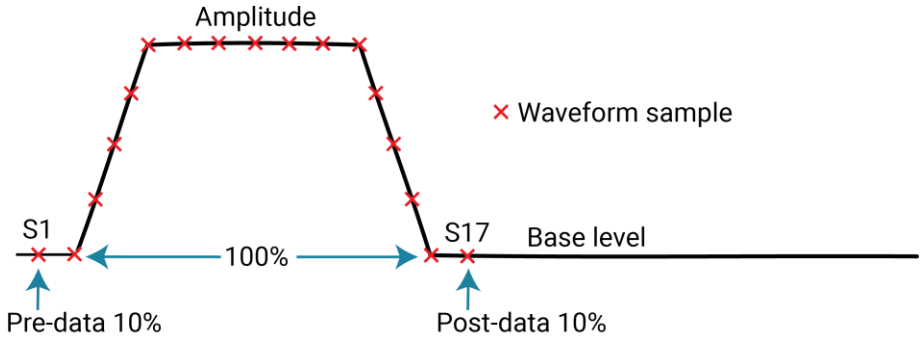


Waveform measurements

Waveform measurement readings sample the entire pulse. Sampling is performed on the rise time, top width, and fall time portions of the pulse. In the following figure, 15 samples are performed on the pulse waveform. Enabled voltage and current readings and timestamps are returned for every sample taken on the pulse. The *NumPulses* (number of pulses) parameter specifies the number of pulses to be output and sampled.

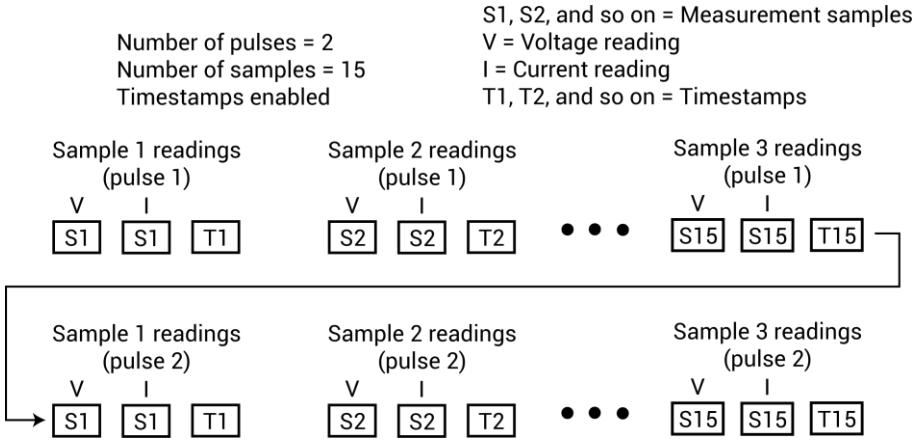


A waveform measurement can include pre-data and post-data. Pre-data is extra data taken before the rise time of the pulse; post-data is extra data taken after the fall time, as shown in the following figure. See Waveform measurement timing (on page 105) for details on measurement timing for pre-data and post-data.



Waveform discrete readings

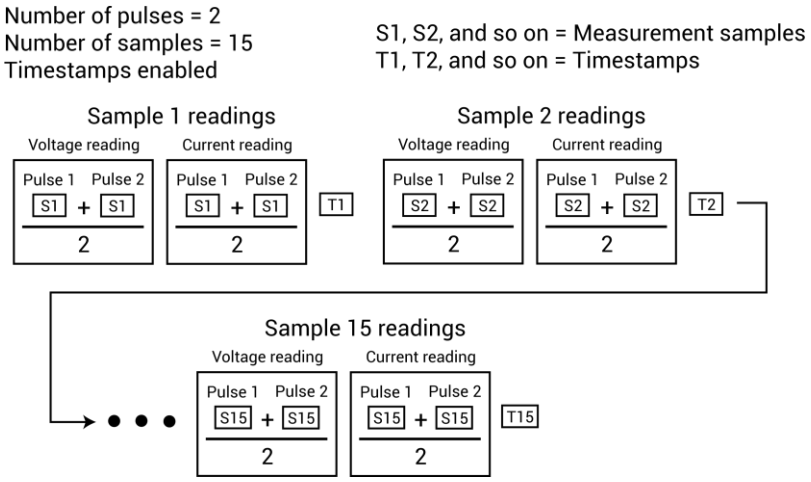
Enabled voltage and current readings and timestamps for every sample of the waveform are returned in a single data set. The following figure shows how waveform discrete readings are returned as a data set for two pulse periods with voltage, current, and timestamp readings enabled.



Waveform average readings

For this data acquisition type, each returned reading is a mean average of the corresponding samples for all the pulses in the burst. For example, in the figure in Waveform discrete readings (on page 103), the V and I readings for sample 1 - pulse 1 would be averaged with the V and I readings for sample 1 - pulse 2.

The following figure shows how waveform average readings are returned as a data set for two pulse periods with voltage, current, and timestamp readings enabled.



Measurement timing

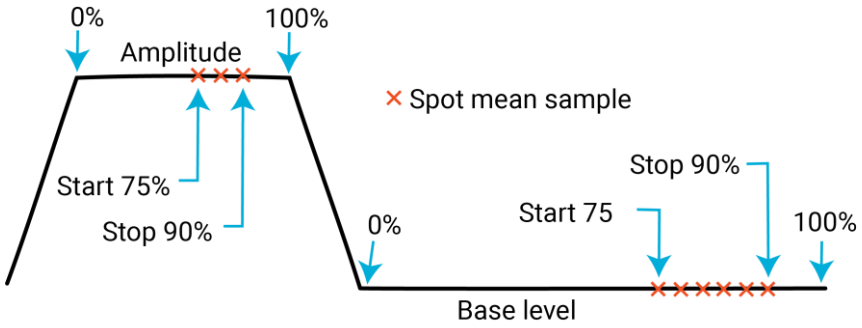
Use the `pulse_meas_timing` function to configure pulse measurement timing.

Spot mean measurement timing

The spot mean measurement type samples a portion of the amplitude and a portion of the base level. The measured samples are then averaged to yield a single voltage and current reading for the amplitude and base low levels. The *`NumPulses`* (number of pulses) parameter specifies the number of pulses to be output and sampled.

The following figure shows that three measured samples are taken on the amplitude and six samples are taken on the base level. The start and stop percentage values indicate the portions of the pulse that are sampled. As shown, the beginning of the amplitude and base level are designated as the zero (0) percent points; the ends are designated as the 100% points. The start and stop points for amplitude and base-level sampling are expressed as a percentage between 0% and 100%. The default is 75% for the start of spot mean and 90% for end of spot mean. These percentages are applied to the total time of the pulse top. In this example, sampling for the amplitude and base levels starts at 60% (0.6) and ends at 80% (0.8).

The number of samples taken on the amplitude and base level is dependent on the size of the portions to be sampled and the sampling rate. Use the `pulse_sample_rate` function to set the sampling rate for pulse measurements.



Spot mean measurement limitations

For some short pulses, the PMU may not produce spot mean measurements because of sample rate limitations. The fastest PMU sample rate is 5 ns.

If the measure window in spot mean is less than < 5 ns, Clarius displays the error, "The specified timing parameters produce pulse high or low measurement segments that are too short to measure."

For example, if the width is 40 ns with a rise and fall that are 20 ns each, the high-level segment width is:

width = width – (rise+fall)/2 = 20 ns

However, because we used only 20% of that segment making measurements, as shown in Spot mean measurement timing (on page 104), the actual width available for measurement is 4 ns, which is below the minimum requirement of 5 ns. To resolve this error, the width of the signal needs to be increased to 50 ns.

Waveform measurement timing

The waveform measurement type samples the pulse as shown in Waveform measurements (on page 102). Sampling is performed on the entire duration (100%) of the pulse. This includes the rise time, amplitude, and fall time portions of the pulse. A voltage and/or current reading is returned for every sample.

A waveform measurement can include pre-data and post-data. Pre-data is extra data taken before the rise time of the pulse. Post-data is extra data taken after the fall time. Waveform measurements (on page 102) shows an example where 10% (0.1) pre-data and 10% (0.1) post-data is taken.

The number of samples taken on the pulse is dependent on the size of the pulse to be sampled and the sampling rate. Use the LPT command `pulse_sample_rate` function to set the sampling rate for pulse measurements.

NOTE

In the function, a percentage must be expressed as its decimal equivalent. For example, specify 50% as 0.5 in the function.

If you are using waveform capture in an ITM test, provide an initial delay that is at least as long as the shortest timing parameter (rise time, pulse width, or fall time).

Example: pulse_meas_sm

This function sets channel 1 of the PMU for the spot mean discrete measure type to acquire the voltage amplitude measurement, the current base level measurement, and the timestamps. It also enables LLEC for amplitude:

```
pulse_meas_sm(PMU1, 1, 0, 1, 0, 1, 0, 1, 1);
```

Where:

- *Instr_id* = PMU1
- *chan* = 1 (channel 1)
- *AcquireType* = 0 (discrete)
- *AcquireMeasVAmpl* = 1 (enable)
- *AcquireMeasVBase* = 0 (disable)
- *AcquireMeasIAmpl* = 1 (enable)
- *AcquireMeasIBase* = 0 (disable)
- *AcquireTimeStamp* = 1 (enable)
- *LLEComp* = 1 (enable)

Example: pulse_meas_wfm

This function sets channel 1 of the PMU for the waveform discrete measure type to acquire the voltage/current readings for the waveform and the timestamps. It also enables LLEC.

```
pulse_meas_wfm(PMU1, 1, 0, 1, 1, 1, 1);
```

Where:

- *Instr_id* = PMU1
- *chan* = 1 (channel 1)
- *AcquireType* = 0 (discrete)
- *AcquireMeasV* = 1 (enable)
- *AcquireMeasI* = 1 (enable)
- *AcquireTimeStamp* = 1 (enable)
- *LLEComp* = 1 (enable)

Example: pulse_meas_timing

This function sets the following pulse measure timing settings for five spot mean measurements for channel 1 of PMU1:

```
pulse_meas_timing(PMU1, 1, 0.6, 0.8, 5);
```

Where:

- *Instr_id* = PMU1
- *chan* = 1 (channel 1)
- *StartPercent* = 0.6 (60%)
- *StopPercent* = 0.8 (80%)
- *NumPulses* = 5 (output one pulse)

Waveform measurement limitations

A PMU test that is configured for waveform measurements may use spot mean adjustment measurements before the final waveform measurement. This happens if any PMU in the test:

- Is configured to have current measurements with autoranging or limited autoranging.
- Requires load line effect compensation.
- Has threshold voltage, current, or power limit enabled.

These additional spot mean adjustment measurements can cause the limitations described in Spot mean measurement limitations (on page 105).

KPulse (for Keithley Pulse Cards)

Keithley Pulse Application

The Keithley Pulse Application (KPulse) is a nonprogramming alternative that you can use to configure and control the installed Keithley pulse cards. You can use it for quick tests that require minimal interaction with other 4200A-SCS test resources.

The KPulse application supports the source-only configuration of 4225-PMU and 4220-PGU 2-channel pulse cards. The 4225-PMU is identified as PMU on the card tab. All other card types are identified as VPU.

NOTE

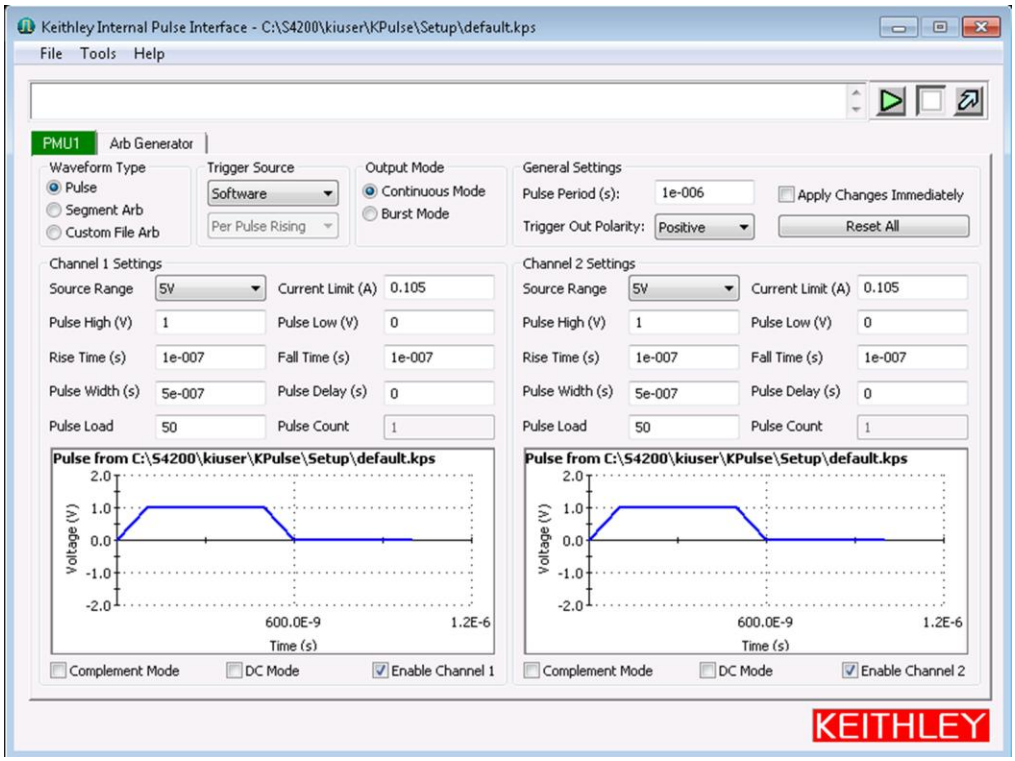
Although KPulse can be launched at the same time as Clarius, KPulse and Clarius cannot communicate with hardware simultaneously.

Starting KPulse

To open KPulse, double-click **KPulse** on the desktop. The following example shows one PMU installed in the system.

From the user interface, each pulse generator can be used to configure and control the following waveform types:

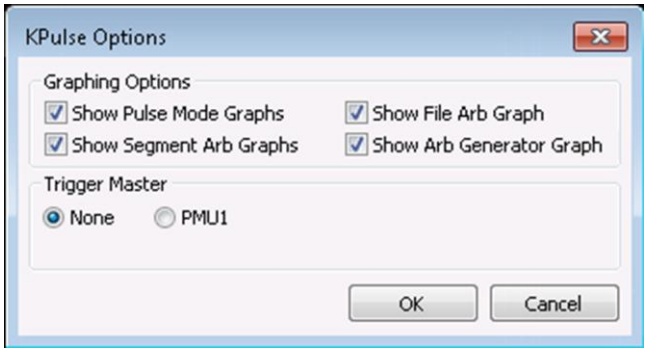
- Standard pulse waveforms (on page 110) and Segment Arb waveforms (on page 112): Pulses are configured and run from the VPU or PMU tabs of KPulse. There is a tab for every Keithley pulse card installed in the 4200A-SCS.
- Custom file arb waveforms (full-arb) (on page 115): Pulses are configured and saved as a `.kaf` file using the Arb Generator tab of KPulse. You can then use the VPU or PMU tab to load the saved `.kaf` file into the pulse generator and run it.



KPulse setup and help

The KPulse menus include:

- **File:** Use this menu to load and save KPulse setups and exit KPulse. By default, setup files are saved at the command path location: `C:\s4200\kiuser\KPulse\Setup`.
- **Tools:** From this menu, select **Options** to open the **KPulse Options** dialog, which includes the following options:
  - **Show Pulse Mode Graphs:** When enabled, shows the Standard Pulse waveform previewers for each pulse card tab.
  - **Show Segment Arb Graphs:** When enabled, shows the Segment Arb pulse waveform previewers for each pulse card tab.
  - **Show File Arb Graph:** When enabled, shows the Custom File Arb pulse waveform previewer for each pulse card tab.
  - **Show Arb Generator Graph:** When enabled, shows the Arb Generator pulse waveform previewer.
  - **Trigger Master:** Select the pulse card that will serve as the trigger master. Select **None** if you are not using a trigger master. See Triggering (on page 110) for more information.



- **Help:** Use this menu to access the Learning Center information and to open the About KPulse dialog.

Triggering

With a Keithley pulse card selected as the trigger master, its Trigger Out can be used to start (trigger) itself or other pulse cards in the system.

NOTE

For the master pulse card, the polarity of the pulse trigger source (`pulse_trig_source`) and pulse trigger polarity (`pulse_trig_polarity`) function must be the same. If you are using a rising-edge trigger source, the pulse trigger polarity must be positive. If you are using a falling-edge trigger source, the pulse trigger polarity must be negative. This requirement applies to all pulse modes, including Standard Pulse, Segment Arb, and Full Arb.

NOTE

When triggering multiple pulse cards in a master/subordinate configuration, changing the trigger output polarity of the master card results in a transition in the trigger output levels that may be interpreted as a trigger pulse by the other cards.

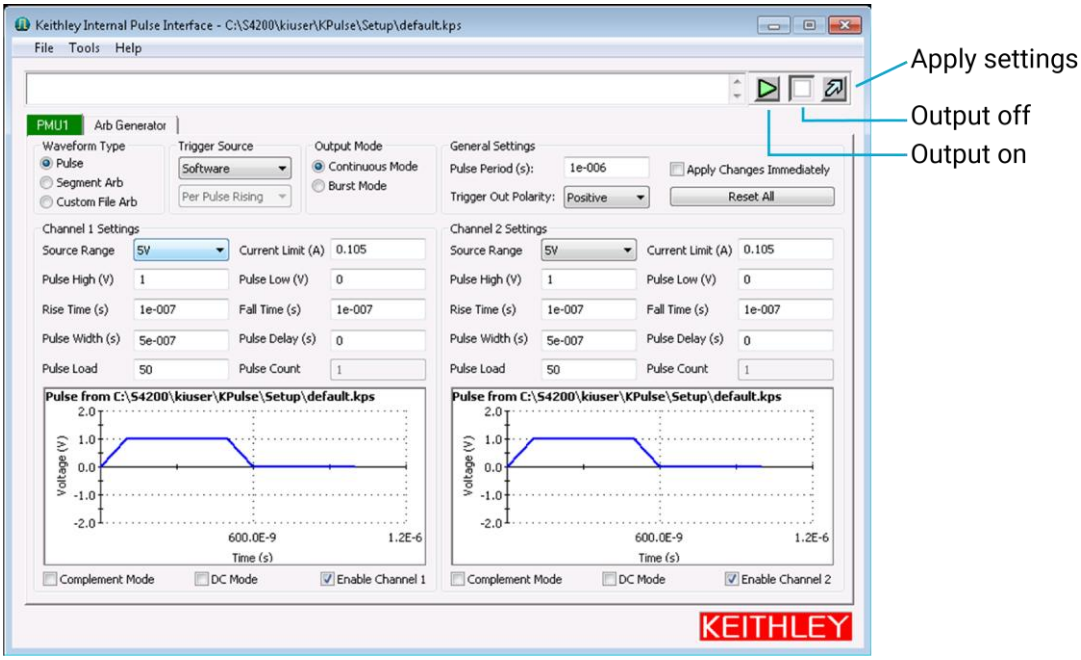
Standard pulse waveforms

Standard pulse waveforms are configured and controlled from the pulse card tabs in the KPulse window. The following figure explains how to use KPulse for a standard pulse output.

Standard pulse waveform previewers: KPulse provides a preview of configured standard pulse waveforms for each enabled channel. Each waveform previewer shows the high and low levels, and timing for the waveform.

In the following figure, the configuration shown in the waveform previewer for Channel 1 uses the default settings for KPulse (pulse high = 1 V and pulse low = 0 V). Channel 2 uses the same settings, but the complement mode is enabled. Pulse high goes to pulse low level (0 V) and pulse low goes to pulse high level (1 V).

The following instructions describe how to use KPulse for a standard pulse output. Repeat these steps for any installed cards that you want to set to standard pulse.



Set waveform, trigger, output, and general settings:

1. Select the pulse card tab (in this example, **PMU1**).
2. For the Waveform Type, select **Pulse**.
3. For the Trigger Source, select **External**.
4. Select the Trigger Source type - **Per Pulse Rising**, **Initial Falling**, **Initial Rising**, or **Per Pulse Falling**.
5. For the Output Mode, select **Continuous Mode** or **Burst Mode**.
6. Under General Settings, set the **Pulse Period** in seconds.
7. Set the Trigger Polarity to **Positive** or **Negative**.
8. Select how to apply the changes by doing one of the following:
   - Select **Apply Changes Immediately** to enable automatic update for pulse output. After the outputs are turned on, the pulse output updates immediately when the settings are changed.
   - Select **Apply Settings** (the button with the light blue arrow) to manually apply settings.

NOTE

Select **Reset All** to return the pulse card to the Standard Pulse waveform type and its default settings. It also updates the previewer.

Configure the Channel 1 and Channel 2 settings:

1. Configure the channel settings as needed. Note that the Pulse Count field is only available if the Output Mode is set to Burst Mode.
2. At the bottom of the window, select **Enable Channel 1** or **Enable Channel 2**. A channel must be enabled to preview its waveform and turn on the output for the channel.
3. If needed, select **DC mode**. This sets the output to fixed DC at the pulse high level. Clear this to return the output to the defined pulse.
4. If needed, select **Complement Mode**. This sets pulse high to the low level and pulse low to the high level.
5. Select the **Output On** button to turn on all enabled channels for all pulse cards installed on the 4200A-SCS. Output Off turns red.
6. To turn off the output, select **Output Off**.

Segment Arb waveforms

Segment Arb™ waveforms are configured and controlled from the PGU or PMU tab in KPulse. The below figure explains how to use KPulse for segment Arb output.

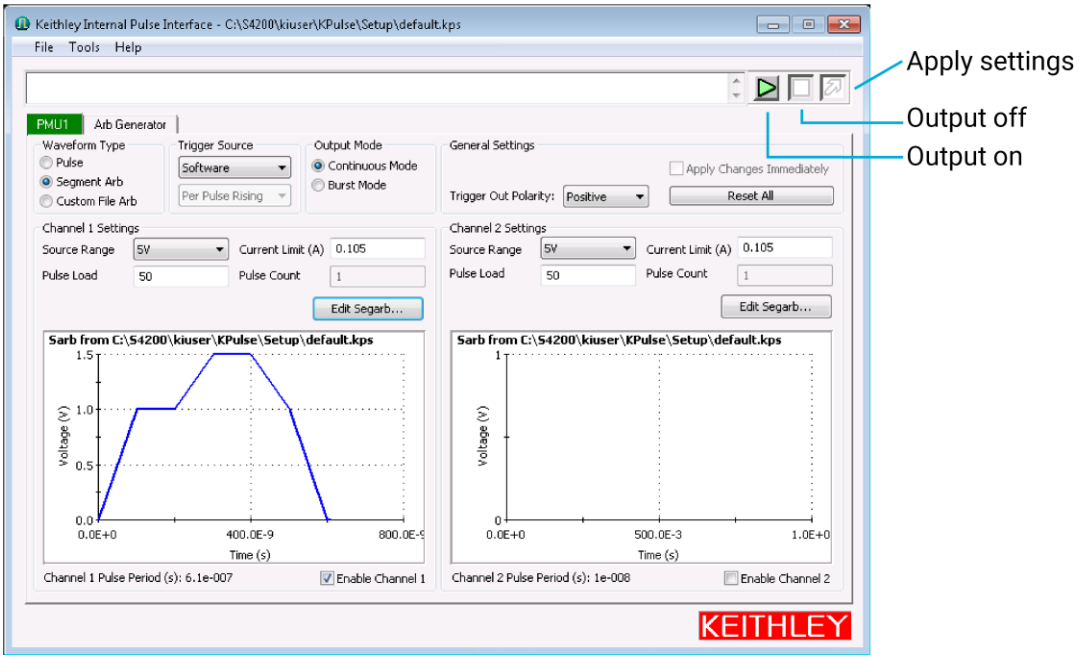
NOTE

Due to the Segment Arb engine overhead, there is an additional 10 ns interval added to the end of the last segment of a Segment Arb waveform. During this interval, the output voltage and trigger output values remain the same as the final value reached in the last segment.

Start, stop, and time restrictions:

- The start level of the first segment and the stop level of the last segment must be the same. In the following figure, Segment 1 start and Segment 7 stop are both set for 0.0 V.
- The stop level for a segment must be the same as the start level for the next segment. In the following figure, the stop level for Segment 1 is 1.0 V, which is the same as start level for Segment 2 (no discontinuities are allowed).
- Time values are in 10 ns increments, with a minimum of 20 ns. For pulse-only waveforms below 20 ns, refer to *Technical Note: Generating 10ns Pulse Widths Using the 4225-PMU*.

Segment Arb pulse waveform previewers: KPulse provides a preview of configured Segment Arb waveforms for each enabled channel. Each waveform previewer shows the segment levels and timing for the waveform.



NOTE

The output trigger levels are not shown in the waveform previewers.

The following instructions describe how to use KPulse for a standard pulse output. Repeat these steps for any installed cards that you want to set to standard pulse.

To set waveform, trigger, output, and general settings:

1. Select the pulse card tab (in this example, **PMU1**).
2. For the Waveform Type, select **Segment Arb**.
3. For the Trigger Source, select **External**.
4. Select the Trigger Source type - **Per Pulse Rising**, **Initial Falling**, **Initial Rising**, or **Per Pulse Falling**.
5. For the Output Mode, select **Continuous Mode** or **Burst Mode**.
6. Under General Settings, set the **Pulse Period** in seconds.
7. Set the Trigger Polarity to **Positive** or **Negative**.
8. Select how to apply the changes by doing one of the following:
   - Select **Apply Changes Immediately** to enable automatic update for pulse output. After the outputs are turned on, the pulse output updates immediately when the settings are changed.
   - Select **Apply Settings** (the button with the light blue arrow) to manually apply settings.

NOTE

Select **Reset All** to return the pulse card to the Standard Pulse waveform type and its default settings. It also updates the previewer.

To configure the Channel 1 and Channel 2 settings:

1. Configure the channel settings as needed. Note that the Pulse Count field is only available if the Output Mode is set to Burst Mode.
2. At the bottom of the window, select **Enable Channel 1** or **Enable Channel 2**. A channel must be enabled to preview its waveform and turn on the output for the channel.
3. Select **Edit Segarb**.
4. For each segment, enter the **Start** voltage, **Stop** voltage, **Time** in seconds, the TTL output **Trig** level (`0` = low; `1` = high), and the state of the **SSR** (solid-state relay, `0` = open, `1` = closed).
5. Select **OK**.
6. Select the **Output On** button to turn on all enabled channels for all pulse cards installed on the 4200A-SCS. Output Off turns red.
7. To turn off the output, select **Output Off**.

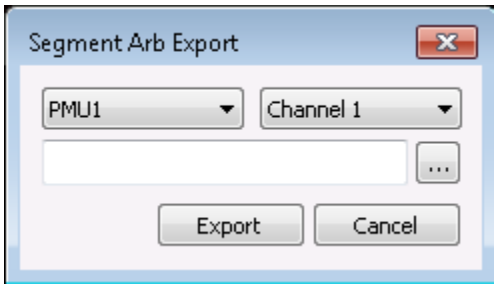
Exporting Segment Arb waveform files

After configuring a Segment Arb™ waveform in KPulse, you can save it as a `.ksf` file. The Segment Arb `.ksf` files should be exported into the `SarbFiles` folder at the following location:

```
C:\s4200\kiuser\KPulse\SarbFiles
```

To export a Segment Arb waveform file:

1. Select **Tools**.
2. Select **Export Segment Arb** to open the Segment Arb Export dialog.



3. Select the pulse card and channel for the waveform to be exported.
4. Select **...**.
5. Locate the target folder.
6. Type a name for the file. The `.ksf` extension is added automatically.

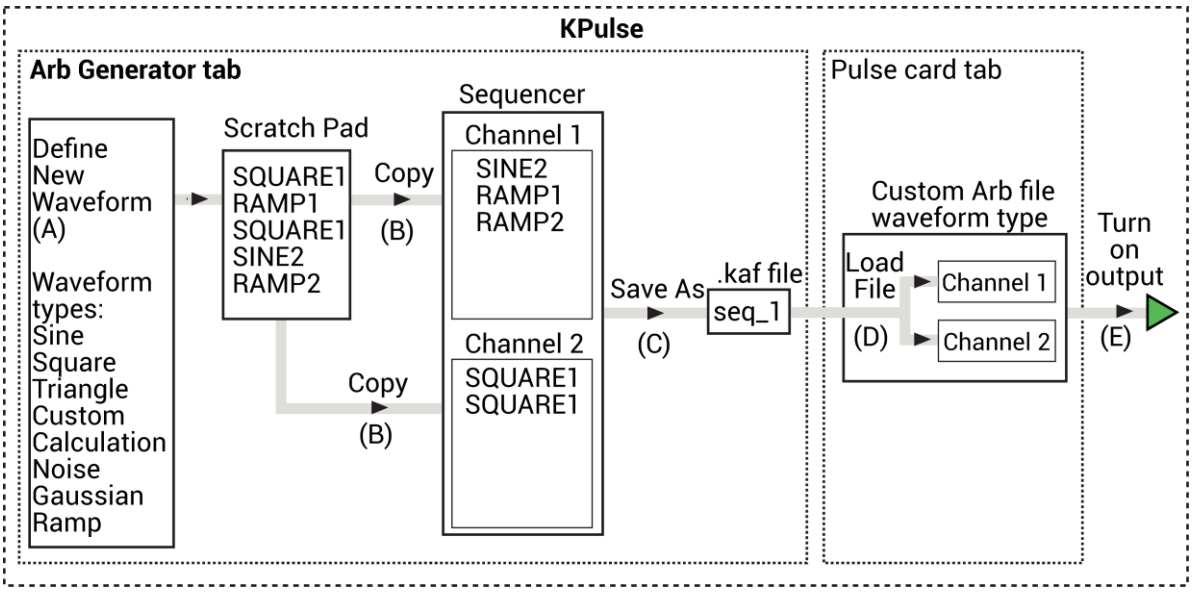
7. Select **Open**.
8. Select **Export**.

You can import a saved `seg_arb.ksf` waveform file into the pulse card using the `seg_arb_file` function.

For segment stress/measure testing, you can import the `.ksf` file through the Clarius Configure pane. For details about segment stress/measure testing, refer to “Segment stressing” in the *Model 4200A-SCS Clarius User Manual*.

Custom file arb waveforms (full arb)

The following figure summarizes the basic processes to create a custom full arb waveform file, to load the file into a pulse card, and to output the pulse waveforms.



To create custom file arb waveforms (full arb):

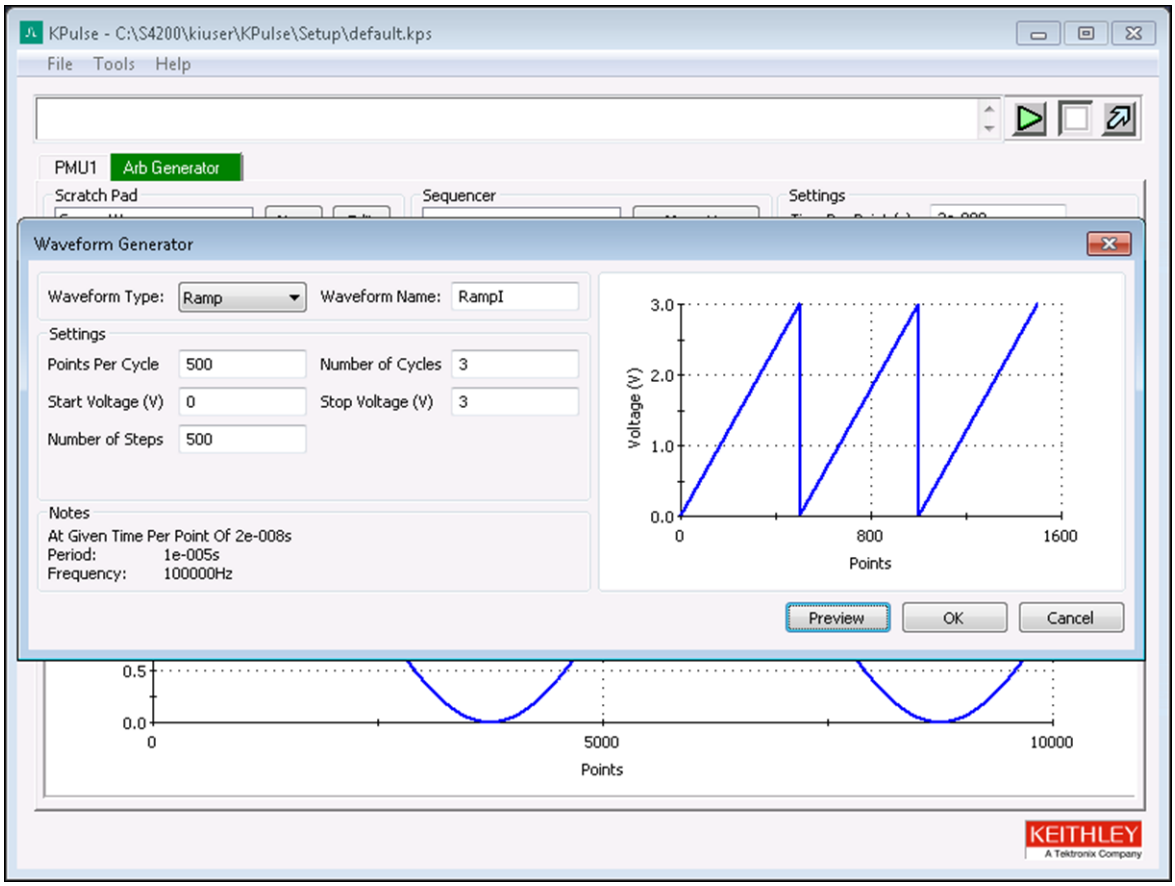
1. Select and configure waveforms.
   - After you select an available waveform type, configure its settings, and name it, the waveform is placed in the Scratch Pad.
   - Waveforms remain in the Scratch Pad until they are deleted by the user.
   - Refer to Waveform types (on page 120) for information about the waveform types available for custom file arb. Refer to Custom Arb file operation: Select and configure waveforms (on page 116) for details.

2. Copy the waveforms into the Sequencer for Channel 1, Channel 2, or both:
   - The order that two or more waveforms appear in a channel sequencer is the order that the waveforms are output by that channel.
   - Refer to Custom Arb file operation: Copy waveforms into Sequencer (on page 117) for details.
3. Save the waveforms in the Sequencer as a `.kaf` file. See Custom Arb file operation: Copy waveforms into Sequencer (on page 117).
4. Load the `.kaf` waveform file into a pulse generator (using the appropriate pulse card tab): Refer to Custom Arb file operation: Load waveform and turn on output (on page 119) for details.
5. Turn on the output for enabled channels. See Custom Arb file operation: Load waveform and turn on output (on page 119).

Custom Arb file operation: Select and configure waveforms

To select and configure waveforms:

1. Select the **Arb Generator** tab.
2. Select **New Waveform** to open the Waveform Generator dialog, shown in the following figure.

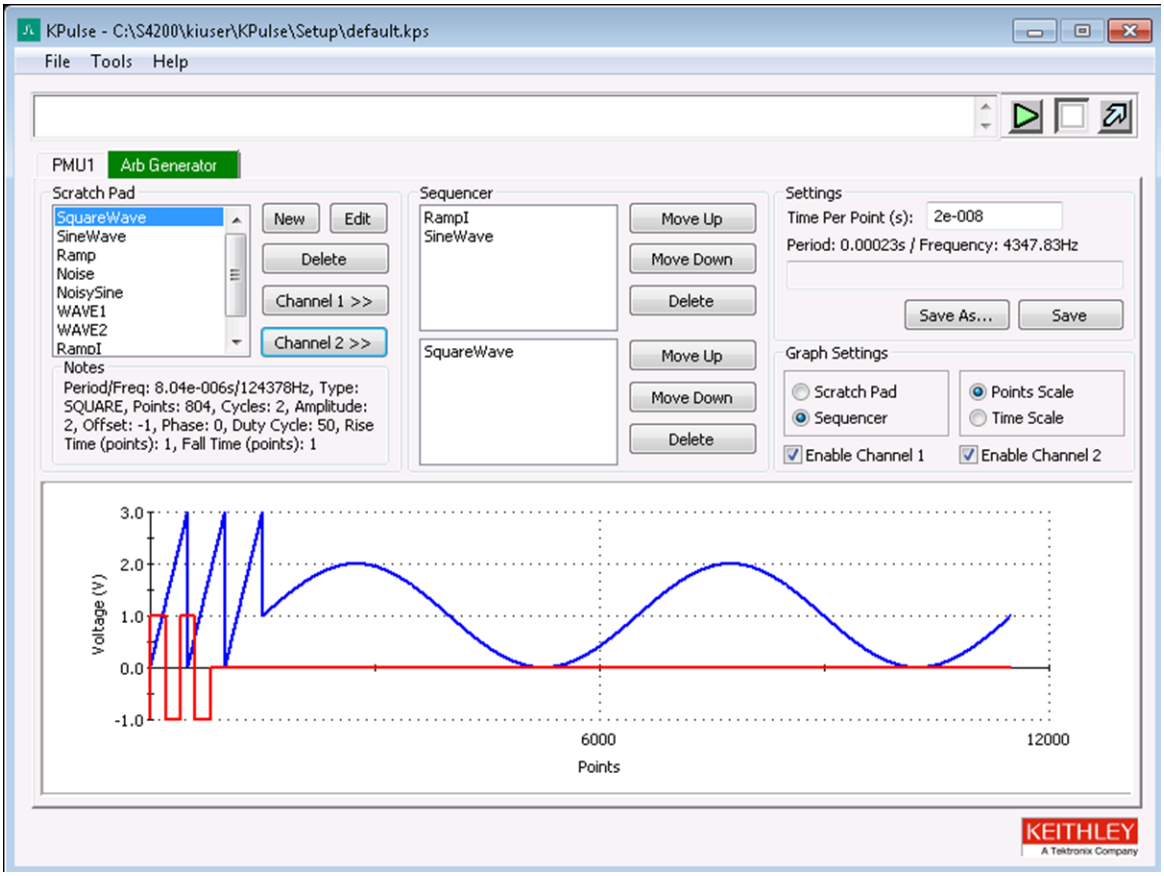


3. Select the **Waveform Type** to be created.
4. Configure the **Settings** for the selected waveform type.
5. Select **Preview** to update the preview of the waveform.
6. In the **Waveform Name** field, type in a name for the waveform. You cannot use a name that is already used in the Scratch Pad.
7. Select **OK** to create the waveform. The new waveform is added to the Scratch Pad.
8. Repeat these steps to create another waveform in the Scratch Pad.

Custom Arb file operation: Copy waveforms into Sequencer

To copy waveforms into the Sequencer:

1. Select the **Arb Generator** tab.
2. Select **Scratch Pad** or **Sequencer**:
   - Scratch Pad previews the waveform that is selected in the Scratch Pad.
   - Sequencer previews enabled waveform sequences. To preview the waveforms in the Sequencer, select **Enable Channel 1** or **Enable Channel 2**.
3. Select the scale for the graph, **Points Scale** or **Time Scale**.
4. In the Scratch Pad, select a waveform to be copied into the Sequencer.
5. Select **Channel 1** to copy the selected waveform onto the Sequencer for Channel 1 or select **Channel 2** to copy the waveform into the Sequencer for Channel 2. You can copy the same waveform to both channels.

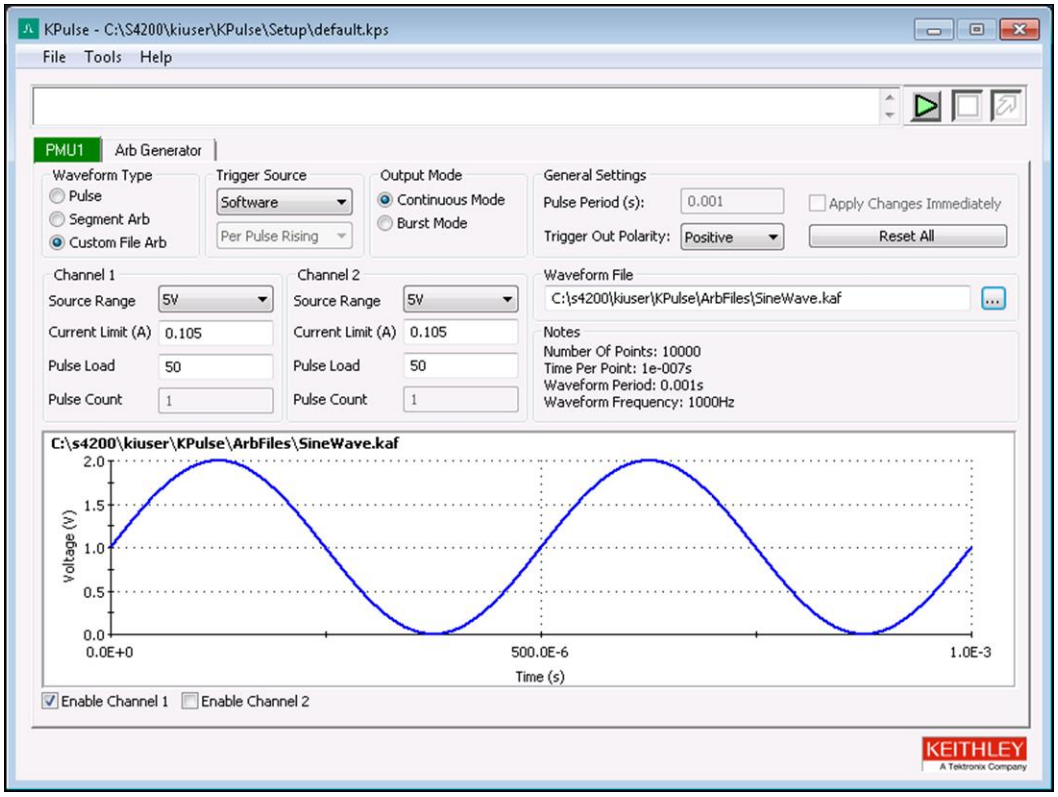


6. To change a waveform sequence, select a waveform in the Sequencer and select **Move Up** or **Move Down**.
7. **Delete** buttons - After selecting a waveform in the Scratch Pad or Sequencer, select the appropriate Delete button to remove it. Note that deleting a waveform from the Scratch Pad also removes it from the Sequencer.
8. Set the **Time per Point** (in seconds). This is the time interval between each point in the waveforms.
9. Save the waveforms as a Keithley Arb File (.kaf). By default, `.kaf` files are saved in the folder: `C:\s4200\kiuser\KPuIse\ArbFiles`
10. Use **Save As** to name the file and save it.
11. After any subsequent changes, select **Save** to overwrite the `.kaf` file.

Custom Arb file operation: Load waveform and turn on output

To load the waveform and turn on the output:

1. Select a pulse card tab.
2. Select **Custom FileArb**.
3. Browse for a **Waveform File** and then select and load the `.kaf` file.



4. **Enable Channel 1** and/or **Enable Channel 2**. The loaded `.kaf` file consists of a waveform for one or both of the channels. If the `.kaf` file was saved with one or both channels enabled, the `.kaf` file loads into this tab with the same channels enabled. A channel must be enabled in order to preview and output its waveform. The waveform for Channel 1 is blue and the waveform for Channel 2 is red.
5. Configure triggers for both channels of the pulse card:
   - **Trigger Source** - **Software**, **External**, or **Internal Bus**. With **External** enabled, select the trigger source: **Initial Falling**, **Initial Rising**, **Per Pulse Falling**, or **Per Pulse Rising**.
   - **Output Mode** - Select the output trigger mode: **Continuous Mode** or **Burst Mode**.
6. Configure the **Channel 1 Settings** and/or **Channel 2 Settings**. The Pulse Count field is active if the Burst Mode is the selected trigger mode.

NOTE

To configure other installed pulse cards for Custom File Arb, repeat steps 1 through 6.

7. Select the green triangle to turn on enabled channels for all installed pulse cards in the 4200A-SCS. With the output on, the square box turns red. To turn off the outputs of all pulse cards, select the red box.

Waveform types

KPulse provides the following fundamental waveform types to use as the building blocks for custom file arb:

- Sine waveform (on page 120)
- Square waveform (on page 121)
- Triangle waveform (on page 121)
- Custom waveform (on page 122)
- Calculation waveform (on page 124)
- Noise waveform (on page 124)
- Gaussian waveform (on page 125)
- Ramp waveform (on page 125)
- Sequences waveform (on page 126)

As explained in Custom Arb file operation: Select and configure waveforms (on page 116), a waveform is created using the Waveform Generator. After selecting and configuring one of the above waveform types, the waveform is placed into the Scratch Pad.

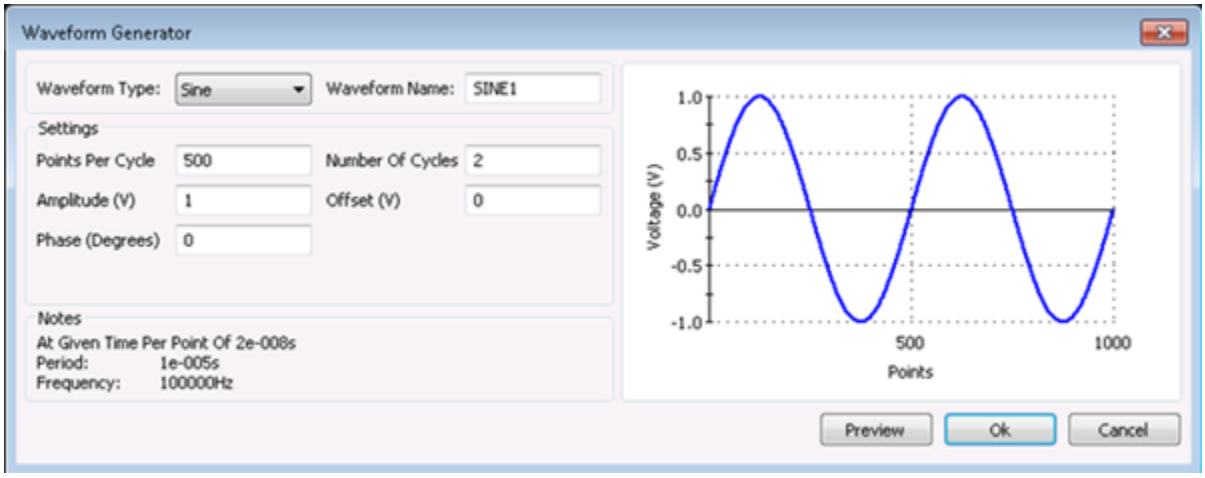
NOTE

The period for the waveforms is determined by the **Time Per Point** setting in the Arb Generator tab (refer to Custom Arb file operation: Copy waveforms into Sequencer (on page 117)).

Sine waveform

An example of a sine waveform is shown in the following figure. The waveform for this example is named SINE1, but can be any name that is not already used in the Scratch Pad.

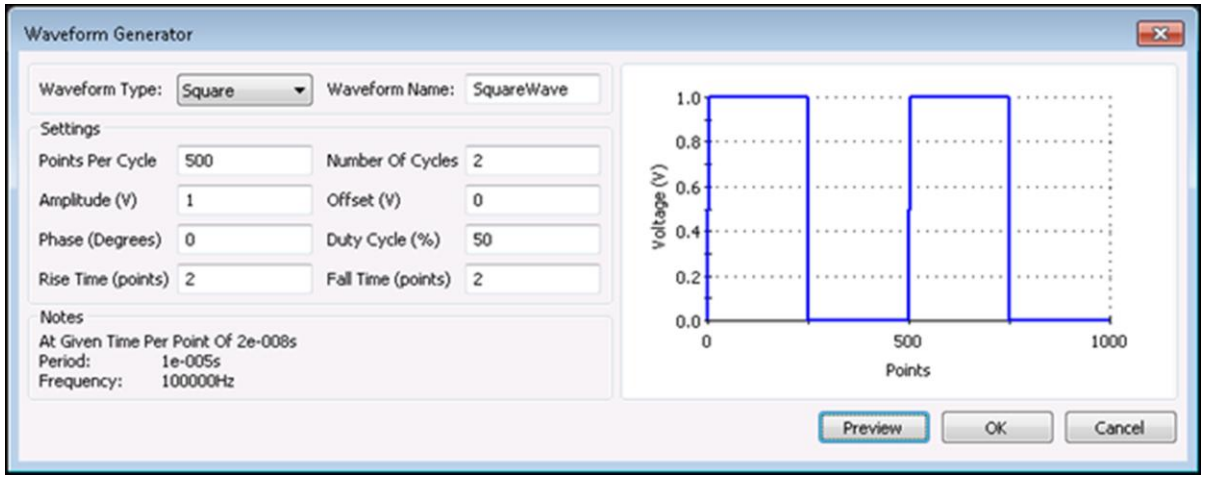
After changing one or more settings, select **Preview** to display the waveform. Select **OK** to place the waveform in the Scratch Pad.



Square waveform

An example of a square waveform is shown in the following figure. The waveform for this example is named WAVE3, but can be any name that is not already used in the Scratch Pad.

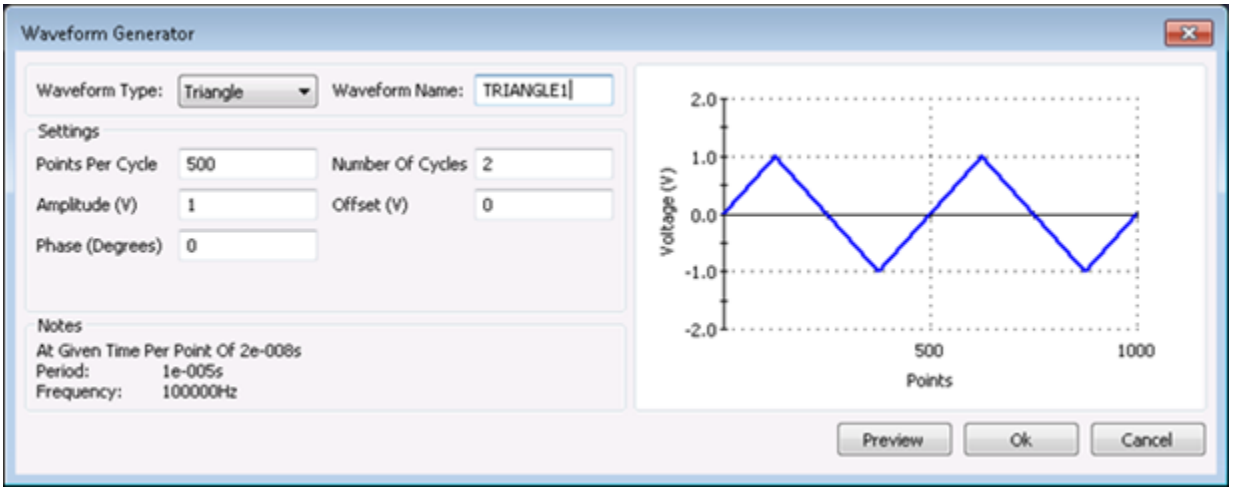
After changing one or more settings, select **Preview** to display the waveform. Select **OK** to place the waveform in the Scratch Pad.



Triangle waveform

An example of a triangle waveform is shown in the following figure. The waveform for this example is named TRIANGLE1, but can be any name that is not already used in the Scratch Pad.

After changing one or more settings, select **Preview** to display the waveform. Select **OK** to place the waveform in the Scratch Pad.

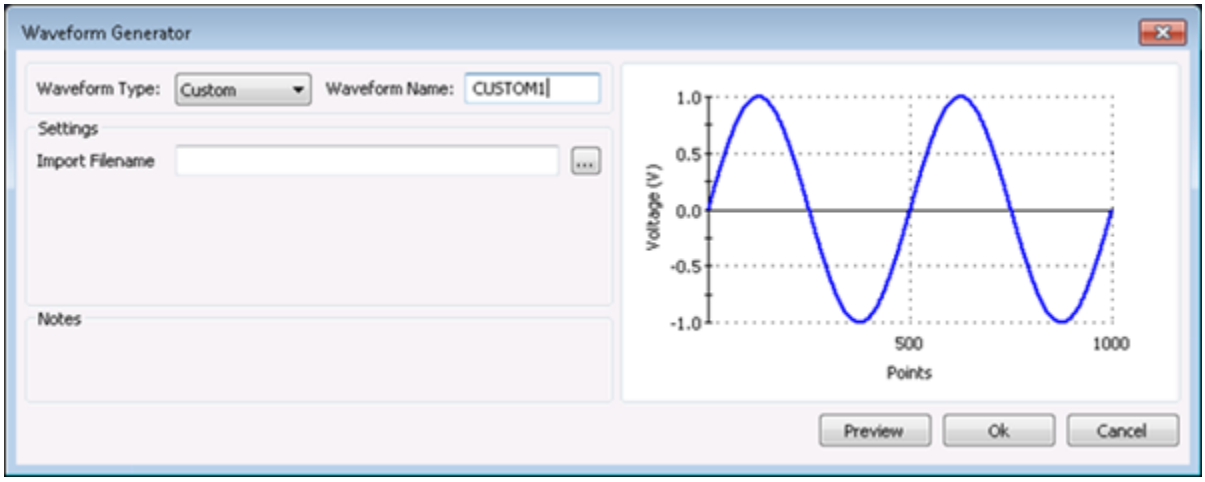


Custom waveform

An example of a custom waveform is shown in the following figure. The waveform for this example is named CUSTOM1, but can be any name that is not already used in the Scratch Pad.

The voltage values for the waveform are retrieved from an imported file (`.txt` or `.csv`). After creating a file (`.txt` or `.csv`) for the custom waveform, use **Import Filename** to import the file into the Waveform Generator.

After importing the file, select **Preview** to show the waveform. Select **OK** to place the waveform in the Scratch Pad.

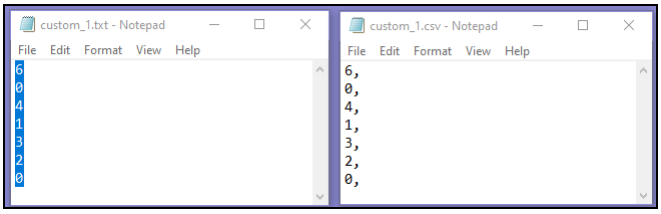


Creating a file (.txt or .csv) for custom waveform

The waveform file is created using a text editor, such as Notepad.

To create the list of voltage points:

1. Open a text editor.
2. On the first line, type the number of voltage points in the waveform, and then type the list (one per line) of values for the waveform:
   - .**txt file format:** As shown in the below figure, commas are not used to separate values.
   - **.csv file format:** As shown in the below figure, commas are used to separate values. Only the first column of data is used for the waveform. Additional columns are ignored.



3. The custom waveform is a simple 6-point waveform made up of these voltage values: 0 V, 4 V, 1 V, 3 V, 2 V, 0 V. Those seven entries are shown in the text editors in the above graphic. The time at each point is determined by the Time Per Point setting in the Arb Generator tab.
4. Save as a waveform file (`.txt` or `.csv`) in the ArbFiles folder at the location:

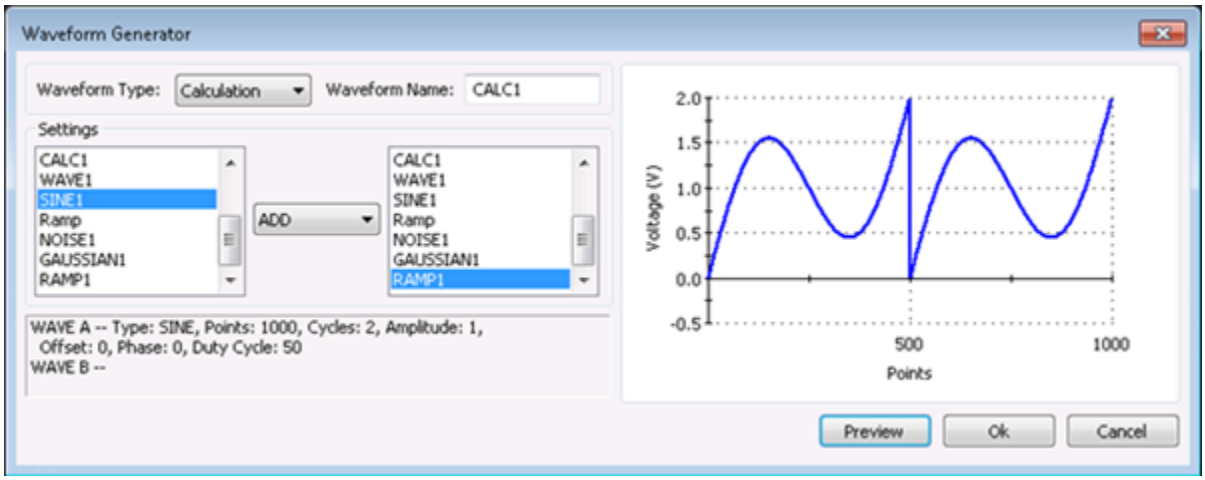
   `C:\s4200\kiuser\KPulse\ArbFiles`

Calculation waveform

An example of a calculation waveform is shown in the following figure. The waveform for this example is named CALC1, but can be any name that is not already used in the Scratch Pad.

The calculation (add, subtract, multiple or divide) performs the selected math operation on two selected Scratch Pad waveforms. In the following example, SINE1 is added to Ramp.

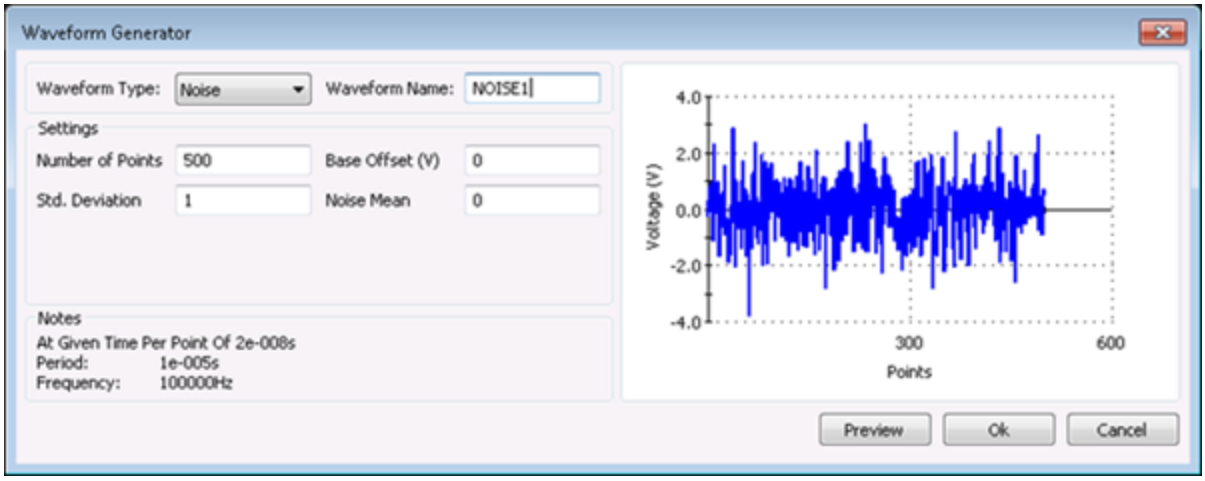
After selecting the two waveforms and the math operation, select **Preview** to display the result of the calculation. Select **OK** to place the waveform in the Scratch Pad.



Noise waveform

An example of a noise waveform is shown in the following figure. The waveform for this example is named NOISE1, but can be any name that is not already used in the Scratch Pad.

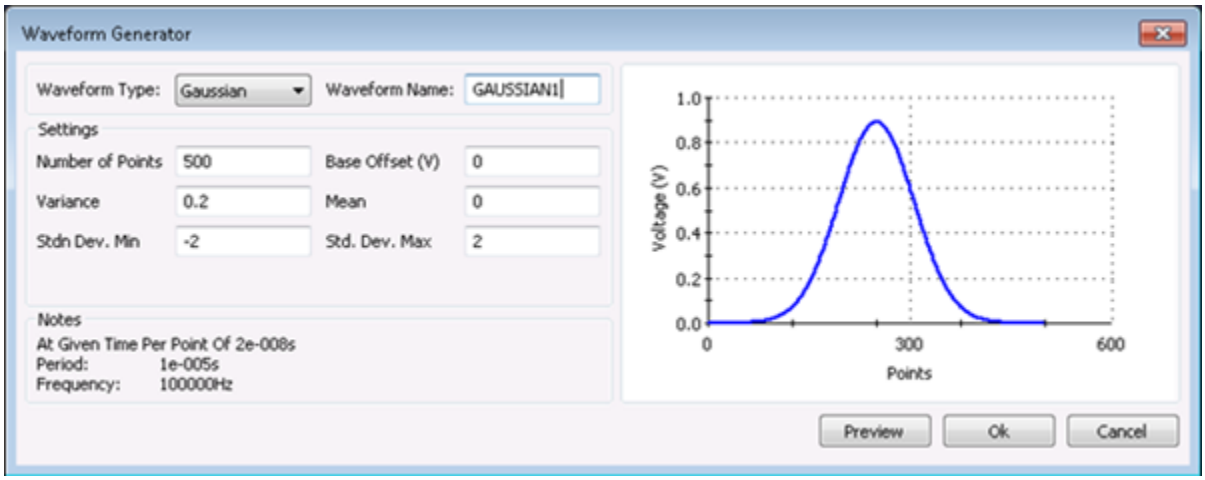
After changing one or more settings, select **Preview** to display the waveform. Select **OK** to place the waveform in the Scratch Pad.



Gaussian waveform

An example of a Gaussian waveform is shown in the following figure. The waveform for this example is named GAUSSIAN1, but can be any name that is not already used in the Scratch Pad.

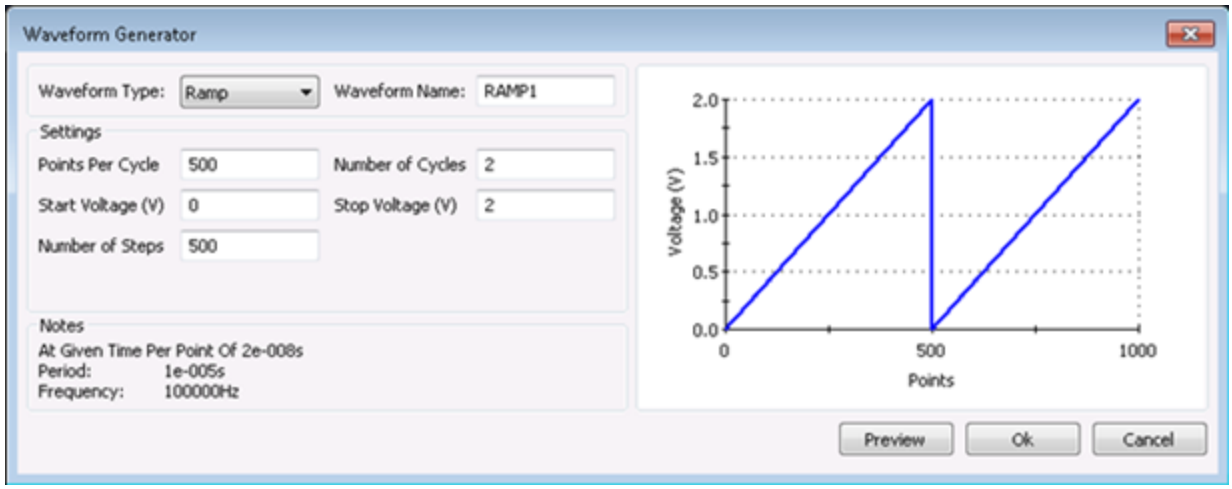
After changing one or more settings, select **Preview** to display the waveform. Select **OK** to place the waveform in the Scratch Pad.



Ramp waveform

An example of a ramp waveform is shown in the next graphic. The waveform for this example is named RAMP1, but can be any name that is not already used in the Scratch Pad.

After changing one or more settings, select **Preview** to display the waveform. Select **OK** to place the waveform in the Scratch Pad.

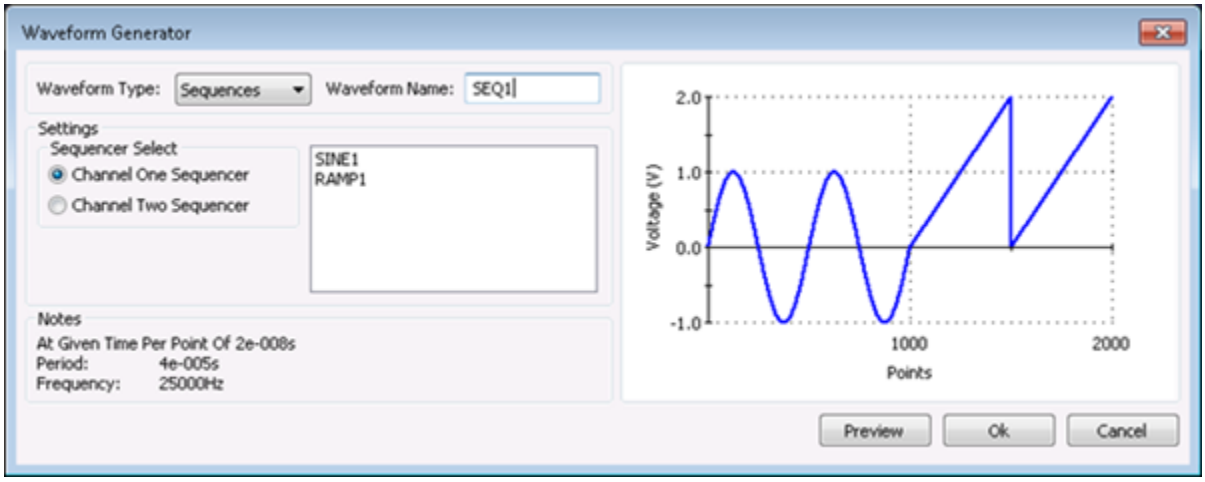


Sequences waveform

An example of a sequences waveform is shown in the below graphic. The waveform for this example is named SEQ1, but can be any name that is not already used in the Scratch Pad.

A sequence waveform consists of the waveforms that are present in the Channel 1 or Channel 2 Sequencer.

After selecting either **Channel One Sequencer** or **Channel Two Sequencer**, select **Preview** to show the waveform. Select **OK** to place the waveform in the Scratch Pad.



Section 6

Use the RPM to switch the SMU, CVU, and PMU

Introduction

The 4225-RPM Remote Amplifier/Switch Module is an accessory for the 4225-PMU UltraFast Pulse Measure Unit that allows you:

- To extend the current measurement ranges of the PMU to the 100 nA range. The RPM adds the following current ranges to the 4225-PMU: 100 nA, 1 µA, 10 µA, 100 µA, 1 mA, and 10 mA.
- To switch automatically between DC I-V, C-V, and pulse I-V measurements without changing cables.

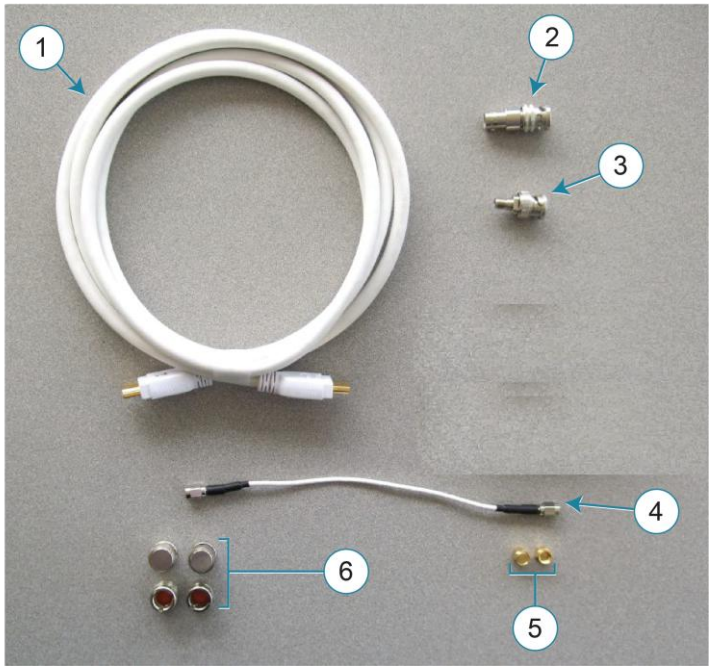
This section provides an example of how to use the 4225-RPM to switch the SMU, CVU, and 4225-PMU and make DC I-V, C-V, and pulse I-V measurements to a single device without having to reconnect the device between measurements.

For this example, you:

- Make connections from two SMUs, one CVU, and the two-channel PMU to the inputs of two 4225-RPMs.
- Make connections from the outputs of the two 4225-RPMs to a diode.
- Generate DC I-V, C-V, and pulse I-V measurements.

Included accessories

The following cables, adapters, and accessories are included in the RPM kit.



Item	Description	Keithley part number	Quantity
1	RPM interconnect cable, 2.4 m (8 ft)	CA-547-2.4	1
2	Triaxial to BNC adapter (guard removed)	CS-712	1
3	BNC-SMA female adapter	CS-1247	1
4	SMA to SMA cable, 20 cm (8 in.)	CA-452	1
5	Protective cap	CAP-47	2
6	Triaxial caps (for shielding, not shorting)	CA-31	4
Not shown	Support bracket	4200-322	1
Not shown	Captive panel screw (for support bracket)	FA-243-2	1
Not shown	Allen socket head capscrew, #4-40 x 5/16"	4-40x5/16SOHBLK	1
Not shown	Hex wrench, 3/32 in.	TL-32	1

Equipment required

- One 4200A-SCS with the following instruments:
  - Two 4200-SMUs, 4201-SMUs, 4210-SMUs, or 4211-SMUs
  - Two 4200-PAs
  - One 4210-CVU or 4215-CVU
  - One 4225-PMU
  - Two 4225-RPMs
- Four 4200-TRX-2 or 4200-MTRX-2 triaxial cables (supplied with SMU)
- Four CA-447B SMA cables (supplied with CVU)
- Two CA-547-2B RPM interconnect cables (supplied with RPM)
- Four CA-534-24B1 triaxial cables
- Two 237-TRX-T triaxial tees
- One shielded test fixture with connection to GNDU (Force LO)

Update the RPM configuration in KCon

The KCon application is used to manage the configuration of the 4200A-SCS, including the 4225-RPM. Before using an RPM for automatic switching, you must update the RPM configuration in KCon. This associates the instruments connected to each RPM and enables automatic switching between tests.

To update the RPM configuration in KCon:

1. Make sure your device under test is disconnected from the RPM output terminals.
2. Close the Clarius application.
3. Open the KCon application.
4. Select **Update**.



5. Select **Save**.
6. Close **KCon**.
7. Open **Clarius**.

Device connections

Using the supplied cables, make connections from the output terminals of the instruments to the input terminals of the two RPMs. Connect the output terminals of the RPMs to the diode in a 4-wire configuration to provide the best measurement accuracy and eliminate the lead resistance effects on I-V and C-V measurements.

⚠ WARNING

Hazardous voltages may be present on all output and guard terminals. To prevent electrical shock that could cause injury or death, never make or break connections from the instrument while the instrument is powered on. Turn off the equipment from the front panel or disconnect the main power cord from the rear of the 4200A-SCS before handling cables. Putting the equipment into an output-off state does not guarantee that the outputs are powered off if a hardware or software fault occurs.
To prevent electric shock, test connections must be configured such that the user cannot come in contact with test leads, conductors, or any device under test (DUT) that is in contact with the conductors. It is good practice to disconnect DUTs from the instrument before powering up the instrument. Safe installation requires proper shields, barriers, and grounding to prevent contact with test lead and conductors.

Connection schematic

The hardware connections from the output terminals of the instruments in the 4200A-SCS are connected to the input terminals of the two 4225-RPMs and then from the output terminals of the two RPMs to the diode under test, as shown in the following figure.

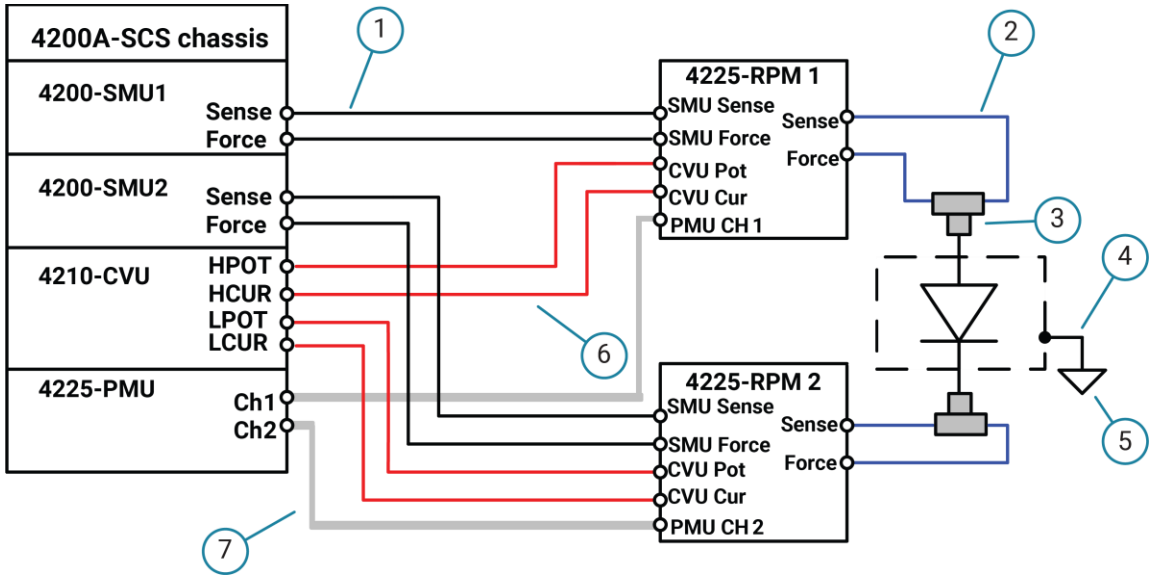
The Sense and Force output terminals of 4200-SMU or 4201-SMU Channel 1 are connected to the SMU Sense and SMU Force connections of 4225-RPM Channel 1 using 4200-TRX-2 or 4200-MTRX-2 triaxial to triaxial cables. The same connection is made between 4200-SMU or 4201-SMU Channel 2 and 4225-RPM Channel 2, using the same cable model.

The HPOT and HCUR output terminals of the 4210-CVU or 4215-CVU are connected to the CVU Pot and CVU Cur inputs of 4225-RPM Channel 1 using CA-447B SMA cables. The LPOT and LCUR output terminals of the CVU are connected to the CVU Pot and CVU Cur inputs of 4225-RPM Channel 2 using CA-447B SMA cables.

The output terminals of the 4225-PMUs are connected to the RPM Control inputs of their respective channels on the 4225-RPMs.

The Force and Sense output terminals from 4225-RPM Channel 1 are connected to the anode of the diode using two triaxial cables (part number CA-534-24B) and a triaxial tee (237-TRX-T). These triaxial cables are rated for accurate low current (I-V) and high frequency (C-V and pulse I-V) measurements.

The output terminals of 4225-RPM Channel 2 are connected to the cathode of the diode using the same cables and triaxial tee as those for Channel 1. To prevent noisy measurements, enclose the diode in a conductive shield connected to the Force LO terminal of the 4200A-SCS.



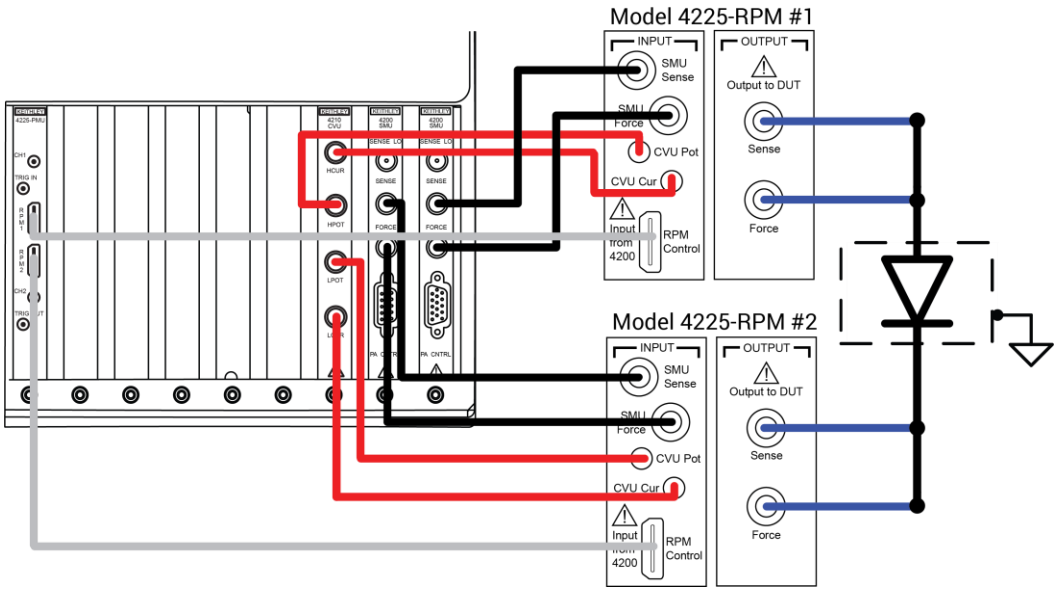
1	4200-TRX-2 or 4200-MTRX-2 triaxial-to-triaxial cables.
2	CA-534-24 triaxial-to-triaxial cables.
3	237-TRX-T triaxial tee.
4	Diode.
5	Diode enclosed in conductive shield connected to Force LO.
6	CA-447B SMA cables.
7	CA-547-2B RPM interconnect cables.

Connect the 4200A-SCS to the DUT

The following figure shows the 4200A-SCS rear panel connections to the input terminals of two 4225-RPMs and from the outputs of the 4225-RPMs to the diode.

NOTE

The diode is enclosed in a conductive shield connected to Force LO of the 4200A-SCS.



Set up the measurements in Clarius

This section describes how to set up the 4200A-SCS to make I-V, C-V, and pulse I-V measurements on a diode. You will create a new project and add a test to the project tree for each measurement type.

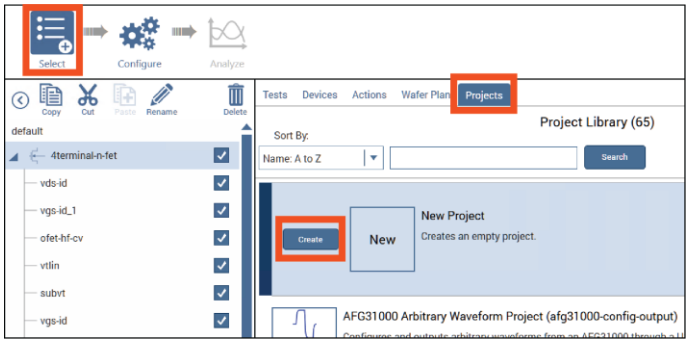
For this example, you use the Clarius application to:

- Create a new project
- Add a device
- Search for and select existing tests in the Test Library
- Configure the tests
- Run the tests
- View and analyze the test results

Create a new project

To create a new project:

1. Choose **Select**.
2. In the Library, select **Projects**.
3. Select **New Project**.
4. Select **Create**.

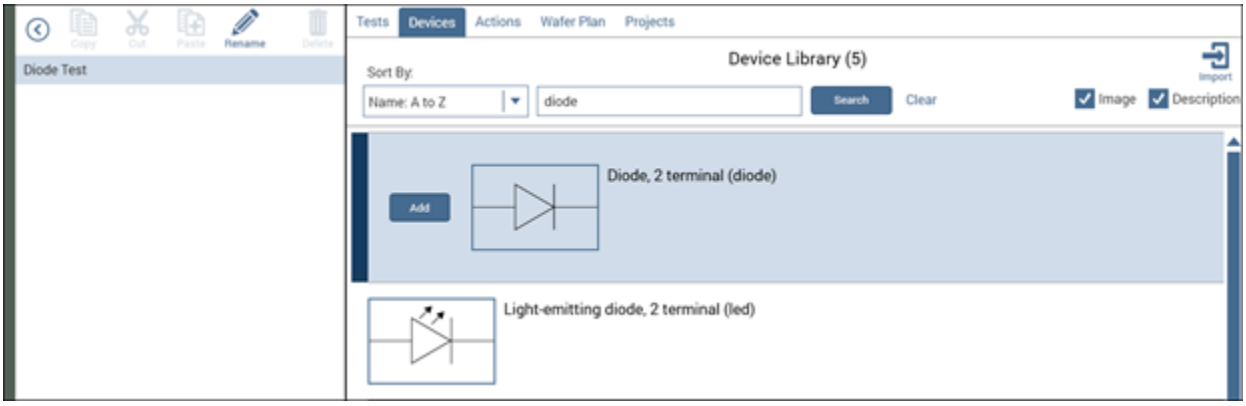


5. Select **Yes** when prompted to replace the existing project.
6. Select **Rename** to assign a new title to the project.
7. Enter `Diode Test`.
8. Select **Enter**.

Add a device

To add a device:

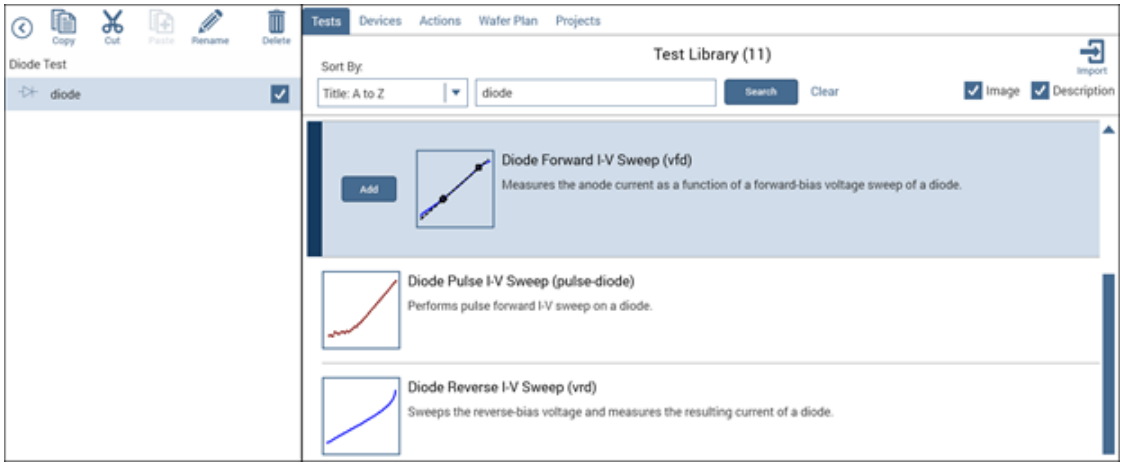
1. Select **Devices**.
2. Type `diode` into the search box.
3. Select **Search**.
4. Select the **Diode, 2 terminal** device.
5. Select **Add** to add it to the project tree.



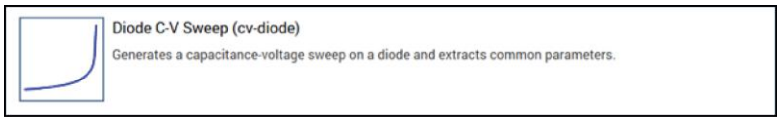
Search for and select existing tests in the Test Library

To search for and select an existing test:

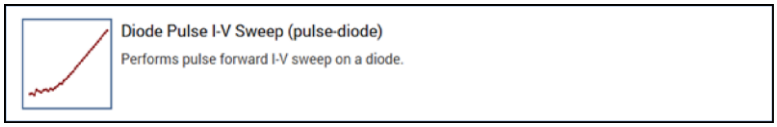
1. Select **Tests**.
2. To find a diode test in the Test Library, type `diode` in the search box, then select **Search**.
3. Scroll to find the `Diode Forward I-V Sweep (vfd)` test.
4. Select **Add** to add the test to the project tree.



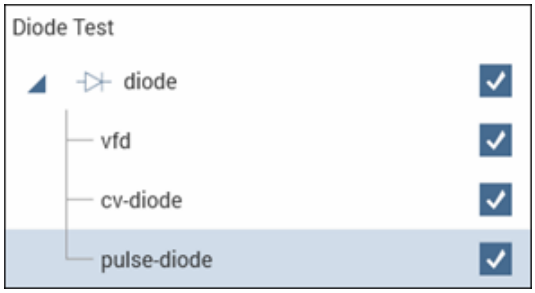
5. Scroll to find the `Diode C-V Sweep (cv-diode)` test.
6. Select **Add** to add this test to the project tree.



7. Scroll to find the `Diode Pulse I-V Sweep (pulse-diode)` test.
8. Select **Add** to add this test to the project tree.



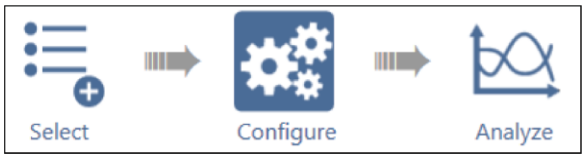
Your project tree now has three tests.



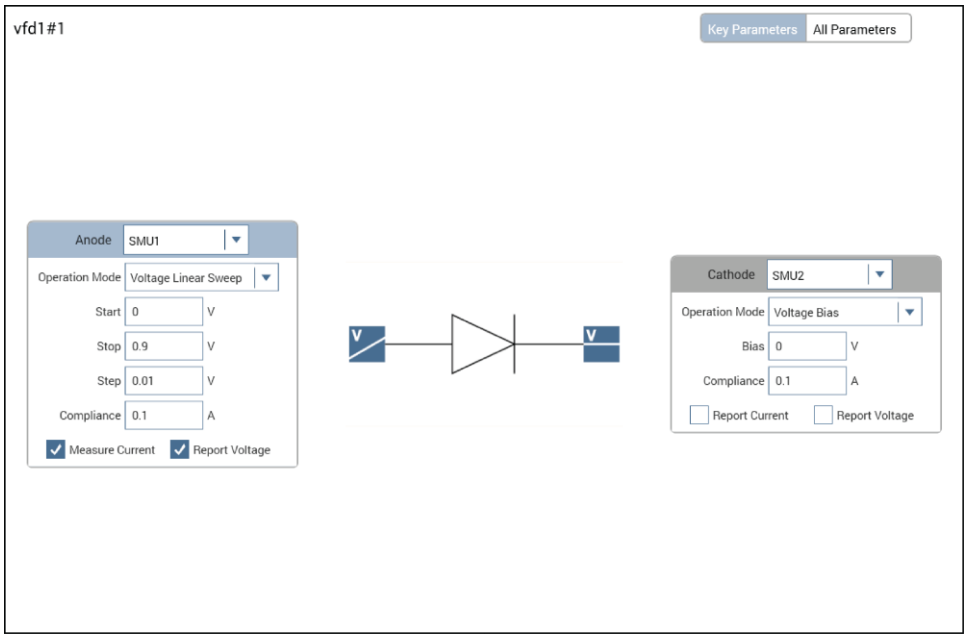
Configure the vfd test

To configure the vfd test:

1. Choose **Configure.**

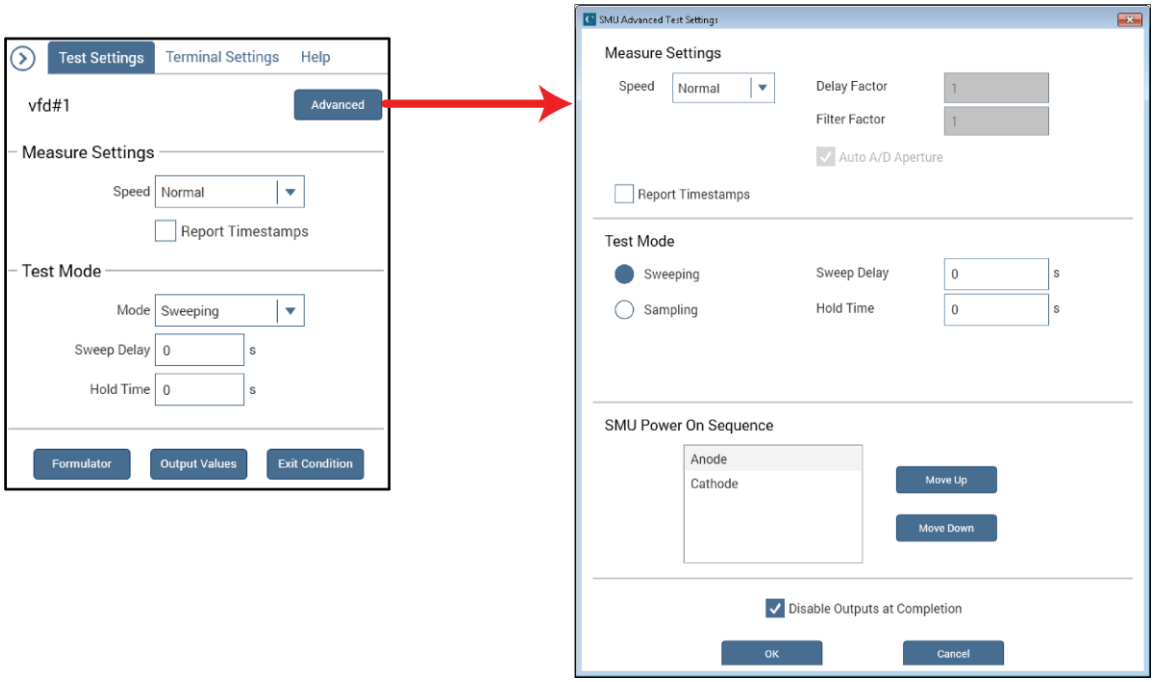


2. In the project tree, select the `vfd` test.
3. Adjust the Anode settings in the Key Parameters pane as needed.

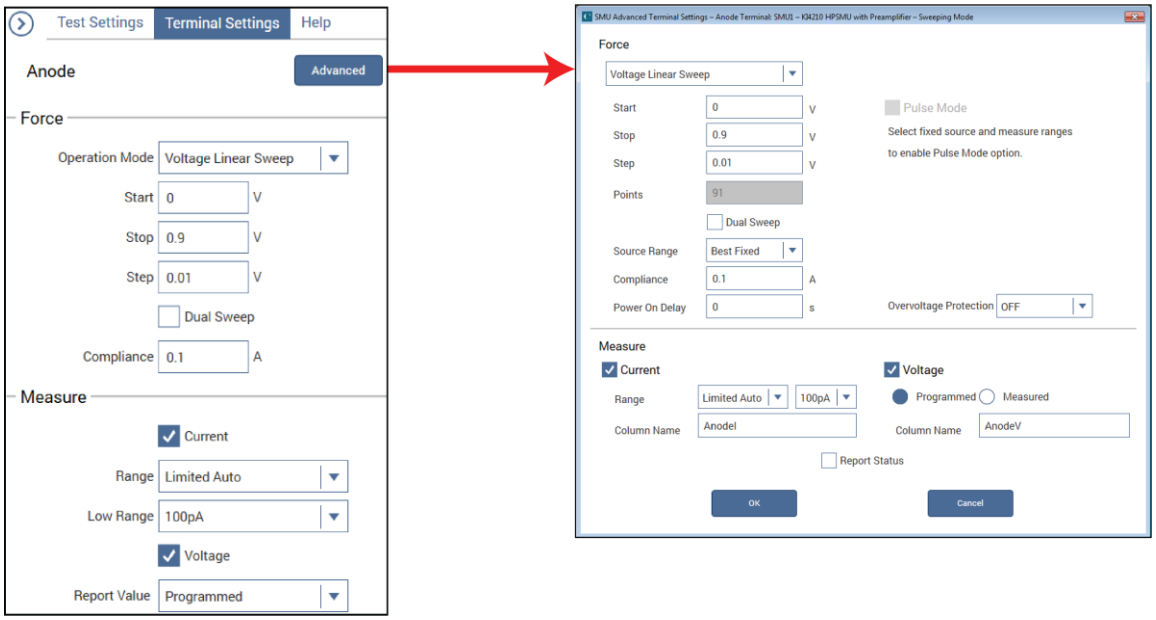


4. In the Test Settings pane, select **Advanced**.

5. Adjust the parameters as needed. Be sure to include the delay between sweep steps.



6. Select **OK** to accept the settings.
7. Select **Terminal Settings**.
8. Select **Advanced**.
9. Adjust the voltage source and current measurement parameters as needed.

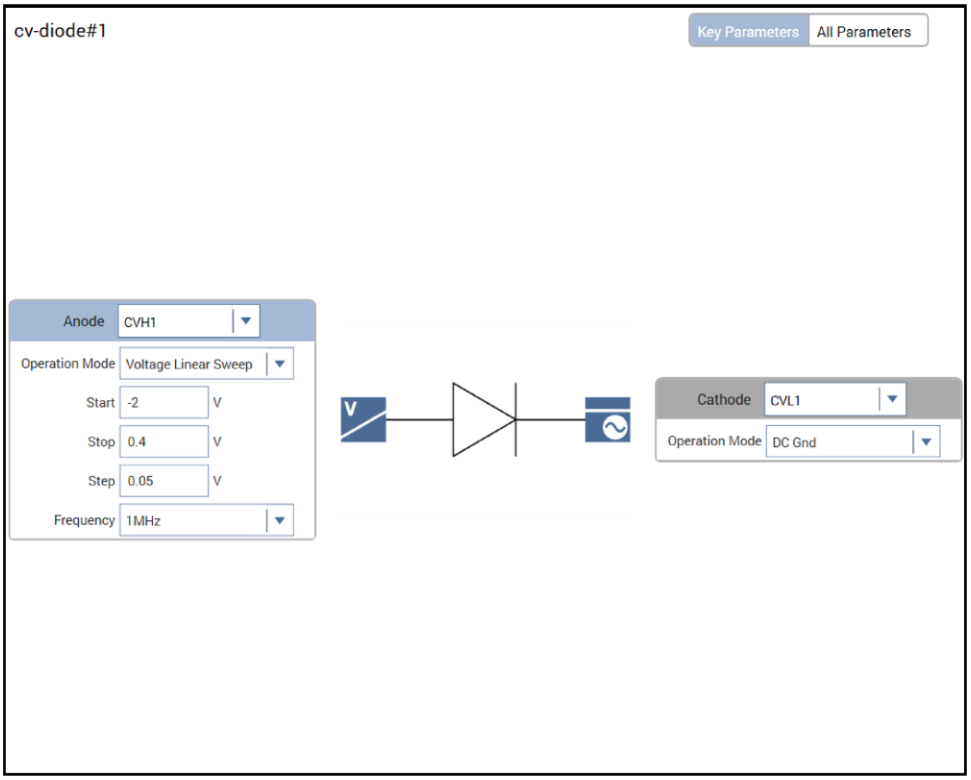


10. Select **OK** to accept the changes.

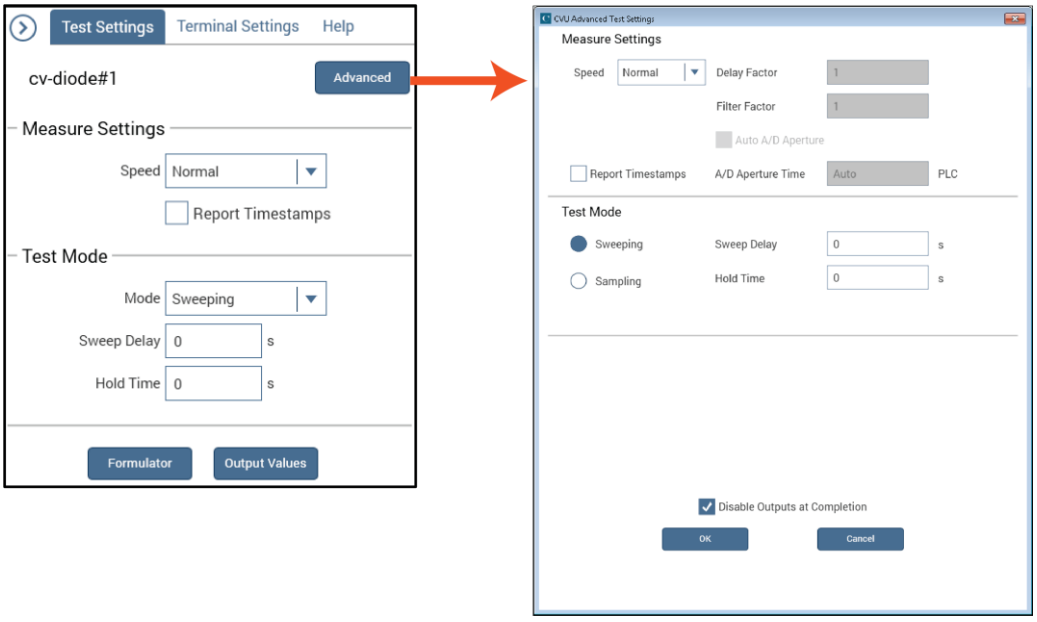
Configure the cv-diode test

To configure the cv-diode test:

1. Select the `cv-diode` test from the project tree.
2. Select the **Anode** terminal of the diode in the Key Parameters pane
3. Adjust the voltage source and test frequency settings as needed.



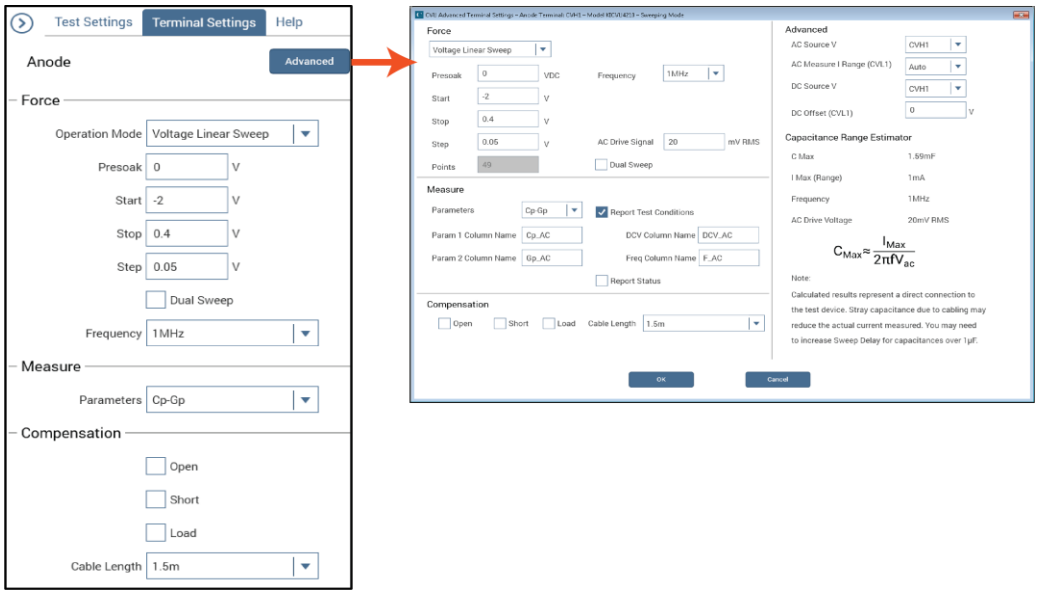
4. On the Test Settings pane, select **Advanced**. Adjust the timing parameters as needed. Be sure to include the sweep delay time in your adjustments.



5. On the Terminal Settings pane and the Terminal Settings Advanced dialog of the Anode terminal, adjust the parameters.

NOTE

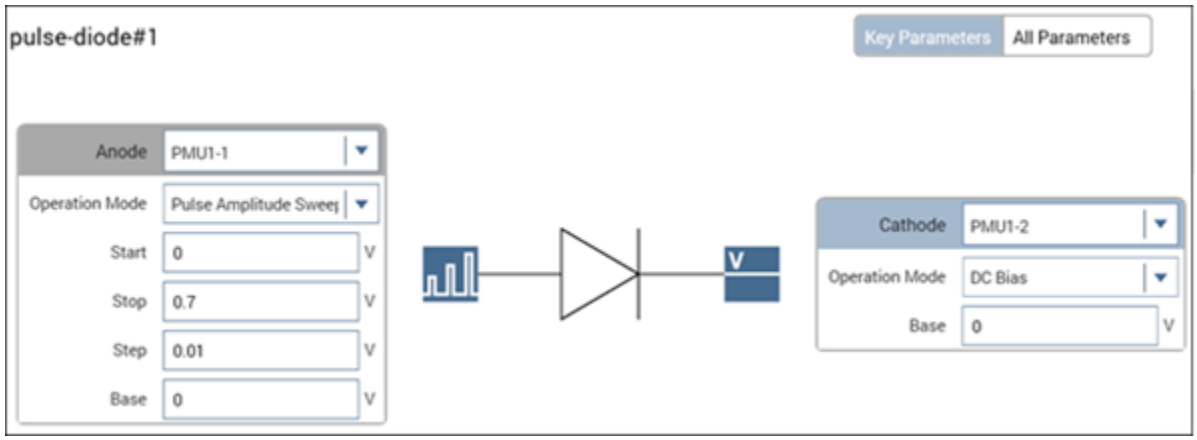
If you are including cable compensation values, run the Tools menu option **CVU Connection Compensation**. Refer to “Perform offset compensation” in the *Model 4200A-SCS Capacitance-Voltage Unit (CVU) User Manual* for more detail.



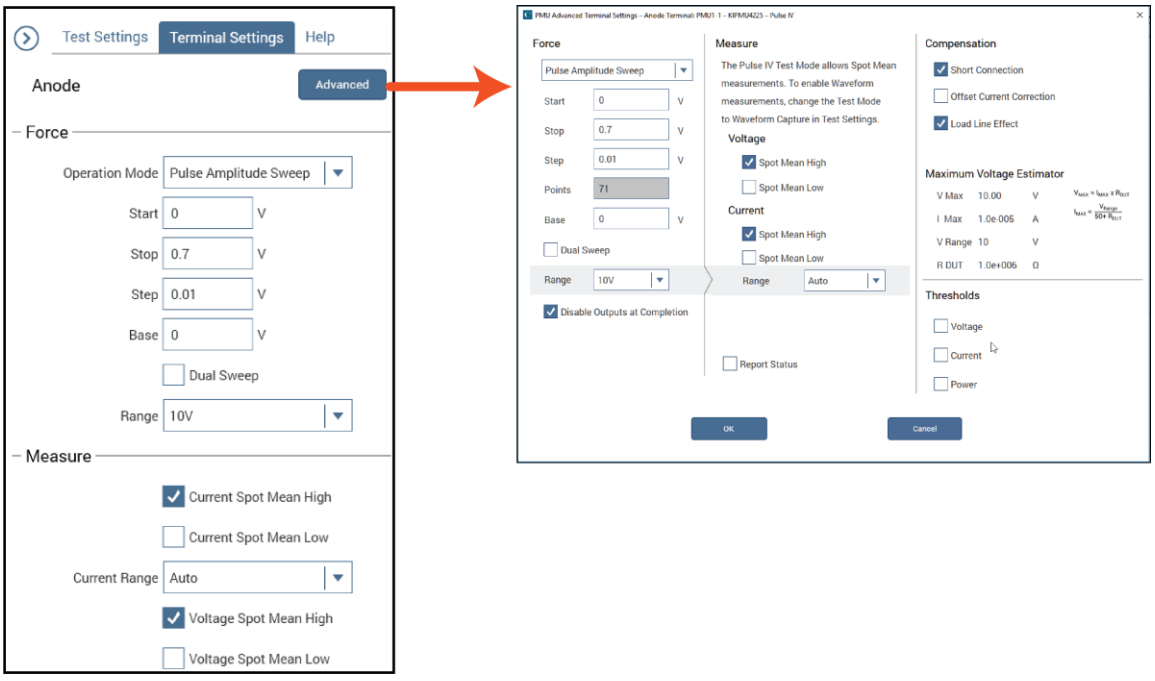
Configure the pulse-diode test

To configure the pulse-diode test:

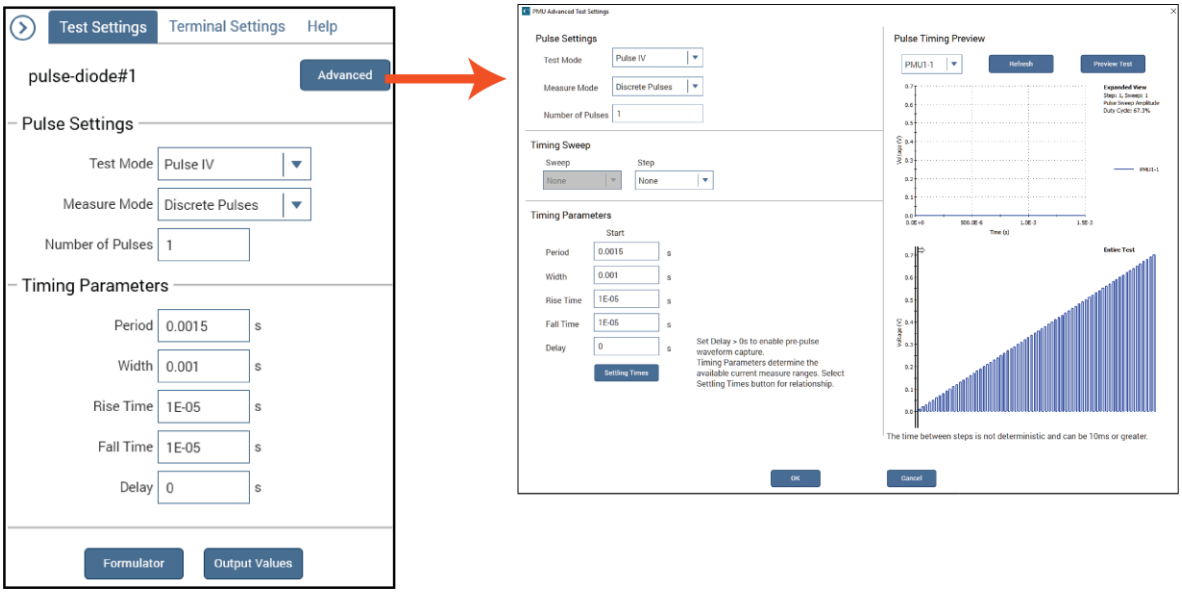
1. In the project tree, select the `pulse-diode` test.
2. From the Key Parameters pane, change the Cathode terminal setting from **PMU1-GND** to **PMU1-2**, as shown in the following figure.
3. Adjust the pulse operation as needed.



4. Select the **Anode** terminal.
5. Select **Terminal Settings**.
6. Select **Advanced** to configure the measurements as needed, including spot mean, PMU compensation, and PMU threshold levels.



7. Select **OK**.
8. Select **Test Settings**.
9. Select **Advanced** to adjust the test mode and pulse timing settings, as needed.



10. Select **OK** to accept the changes.

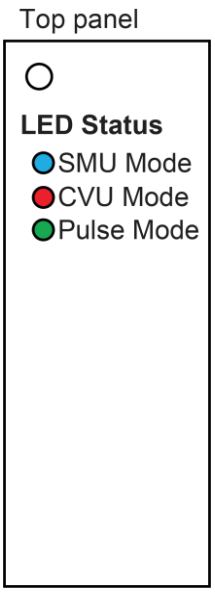
Run the test

Once the tests have been configured, you can execute every test under the device.

To run the tests for the device:

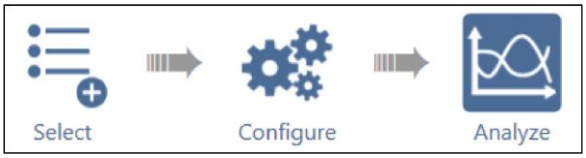
1. Select the diode device in the project tree.
2. Verify that the check boxes for the tests and the device are selected.
3. Select **Run**. The three tests run sequentially and the RPM automatically switches the outputs between the SMU, CVU, and PMU.
4. Select the **Analyze** pane to see the results.

As the instruments switch between tests, the LEDs at the top of the RPMs change color. When the output is connected to the SMU, the LED is blue. When the output is connected to the CVU, the LED is red. When the output is connected to the PMU, the LED is green, which is also the default state.

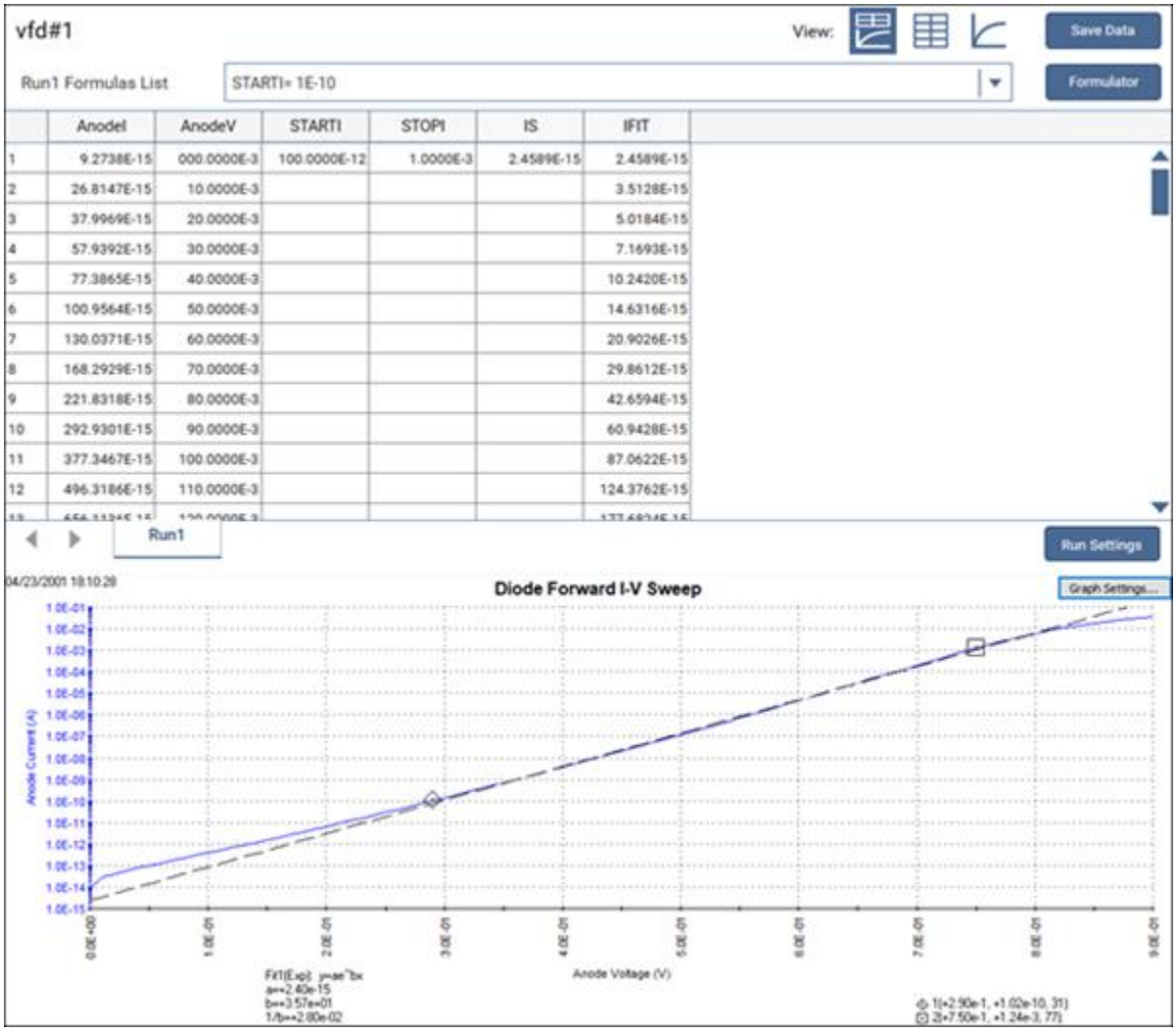


View and analyze the test results

When you run the project, you can select **Analyze**, shown in the following figure, to view test results in real time.



Select a test from the project tree to display its results. The data for the `vfd` test is displayed in the following figure. Both the data and the graph are displayed in this view.


vfd#1
View:
Save Data
Formulator
Run1 Formulas List
STARTI= 1E-10
Anode1 AnodeV STARTI STOPI IS IFIT
1 9.2738E-15 000.0000E-3 100.0000E-12 1.0000E-3 2.4589E-15 2.4589E-15
2 26.8147E-15 10.0000E-3 3.5128E-15
3 37.9969E-15 20.0000E-3 5.0184E-15
4 57.9392E-15 30.0000E-3 7.1693E-15
5 77.3865E-15 40.0000E-3 10.2420E-15
6 100.9564E-15 50.0000E-3 14.6316E-15
7 130.0371E-15 60.0000E-3 20.9026E-15
8 168.2929E-15 70.0000E-3 29.8612E-15
9 221.8318E-15 80.0000E-3 42.6594E-15
10 292.9301E-15 90.0000E-3 60.9428E-15
11 377.3467E-15 100.0000E-3 87.0622E-15
12 496.3186E-15 110.0000E-3 124.3762E-15
Run1
Run Settings
04/23/2001 18:10:28
Diode Forward I-V Sweep
Graph Settings...
Anode Current (A)
Anode Voltage (V)

Section 7

PMU for pulse I-V measurements on a MOSFET

Introduction

You can use the Model 4225-PMU Ultra-Fast Module to make both pulse I-V measurements and transient I-V measurements (waveform capture) on a device.

Pulse I-V refers to a test with a pulsed voltage source and a corresponding high speed, time-based current measurement that provides DC-like results. You can define the parameters of the pulse, including the pulse width, duty cycle, rise/fall times, and amplitude.

Transient I-V, or waveform capture, is a time-based current and/or voltage measurement that is typically the capture of a pulsed waveform. Transient I-V measurements can be used to test a dynamic test circuit or as a diagnostic tool for choosing the appropriate pulse settings in the pulse I-V mode.

This section provides an example of how to use the 4225-PMU and the optional Model 4225-RPM Remote Preamplifier/Switch Module to make a pulse I-V measurement on a MOSFET. The example explains how to set up a pulsed voltage step applied to the gate terminal using PMU1 channel 1 and a pulsed voltage sweep to the drain terminal using PMU1 channel 2. The drain current is measured as a function of the drain voltage and displayed in the graph in the Analyze pane.

Equipment required

One 4200A-SCS with the following instruments and accessories:

- One 4225-PMU
- Two 4225-RPMs
- Two 4200-PRB-C or CA-426D SMA to SSMC Y adapter cables (supplied with the 4225-PMU)
- Two CA-547-2B RPM interconnect cables (supplied with the 4225-RPM)
- Two 7078-TRX-GND plug triaxial to socket BNC adapters, guard removed
- Two CS-1247 plug BNC to socket SMA adapters (supplied with the 4225-RPM)
- Two CA-452A SMA to SMA cables (supplied with the 4225-RPM)
- Two 7078-TRX-GND plug triaxial to socket BNC adapters, guard removed

Device connections

Using the supplied cables, make connections from the output terminals of the two 4225-RPMs to the MOSFET.

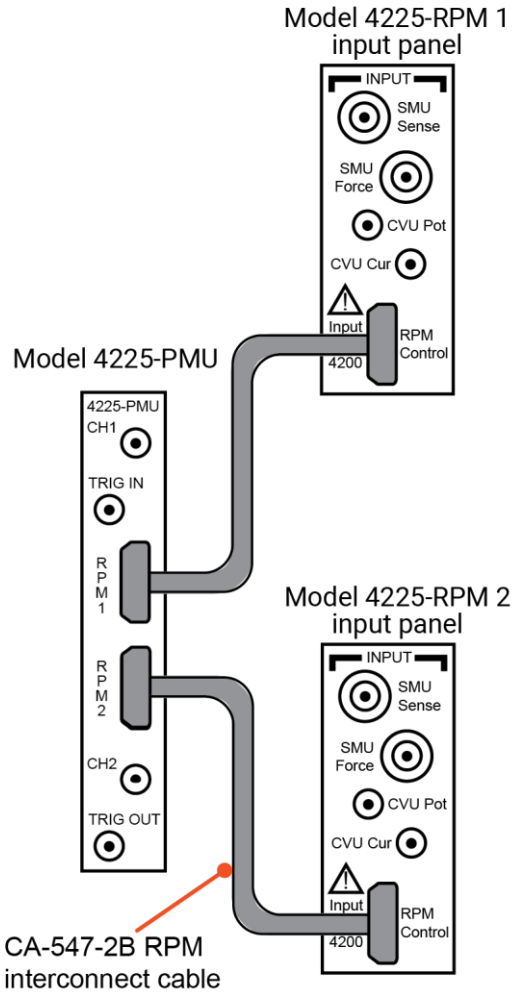
⚠ WARNING

Hazardous voltages may be present on all output and guard terminals. To prevent electrical shock that could cause injury or death, never make or break connections from the instrument while the instrument is powered on. Turn off the equipment from the front panel or disconnect the main power cord from the rear of the 4200A-SCS before handling cables. Putting the equipment into an output-off state does not guarantee that the outputs are powered off if a hardware or software fault occurs.
To prevent electric shock, test connections must be configured such that the user cannot come in contact with test leads, conductors, or any device under test (DUT) that is in contact with the conductors. It is good practice to disconnect DUTs from the instrument before powering up the instrument. Safe installation requires proper shields, barriers, and grounding to prevent contact with test lead and conductors.

Connection schematic

The hardware connections from the output terminals of the PMU and the two RPMs to the MOSFET are shown in the following figures.

Connect one CA-547-2B RPM interconnect cable from each PMU channel to the appropriate RPM.



At the output of each RPM, connect the triaxial to BNC adapter, BNC to SMA adapter, and then the SMA-to-SMA cable.

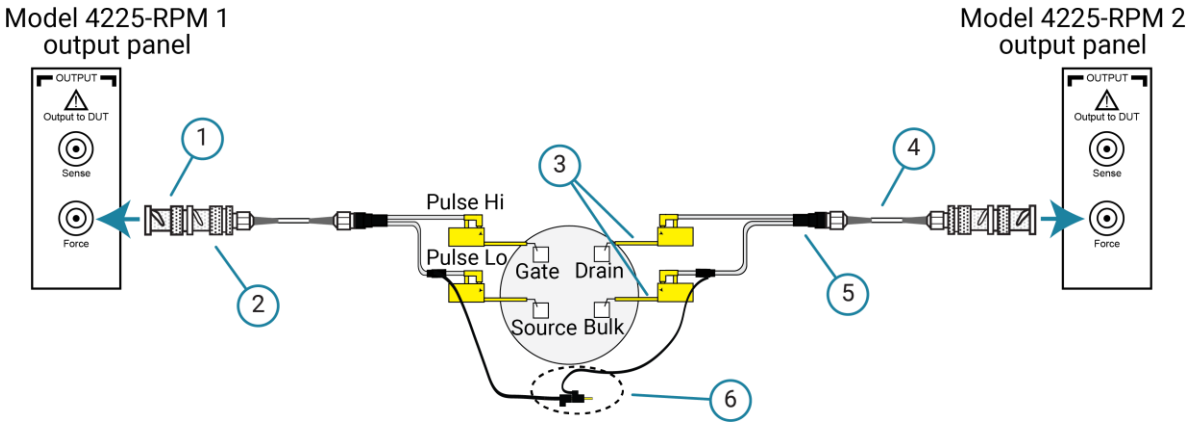
Connect the SMA cables to either probes or a test fixture that is connected to the MOSFET. RPM1 is connected to the gate of the MOSFET and RPM2 is connected to the drain of the MOSFET.

The shields of the SMA cables are the PMU LO connection and must be connected to the source and bulk terminals of the MOSFET. The shields of the two SMA cables should be connected together as close as possible to the device.

The example below illustrates connections from the RPMs to the SMA to SSMC adapter cables (CA-426D or 4200-PRB-C) and then to the probes and device terminals on a wafer.

NOTE

This connection method eliminates triaxial guard (inner shield).



1	Triaxial to BNC adapter.
2	BNC to SMA adapter.
3	Needle holders.
4	SMA to SMA cable.
5	SMA to SSMC adapter cable (CA-426D or 4200-PRB-C).
6	When using more than one SMA to SSMC adapter cable, make sure that all local grounds are connected.

Set up the measurements in Clarius

This section describes how to set up the Clarius application to make a pulse I-V sweep on a MOSFET.

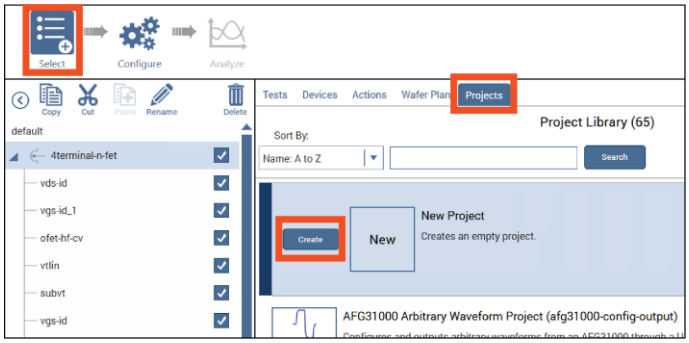
For this example, you use the Clarius application to:

- Create a new project
- Search for and select an existing test
- Configure the test
- Run the test and analyze the results

Create a new project

To create a new project:

1. Choose **Select**.
2. In the Library, select **Projects**.
3. Select **New Project**.
4. Select **Create**.

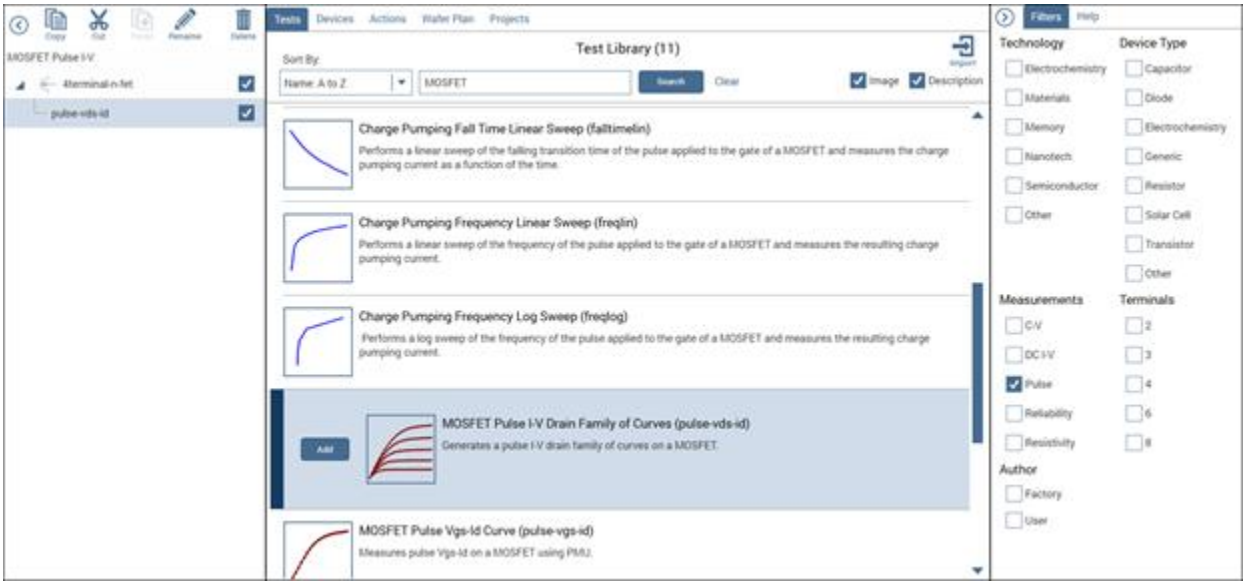


5. Select **Yes** when prompted to replace the existing project.
6. Assign a new title to the project by selecting **Rename** and then entering `MOSFET Pulse I-V`.
7. Select **Enter**.

Search for and select an existing test

To search for and select an existing test:

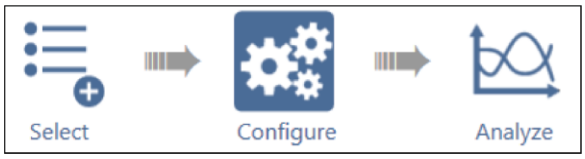
1. Select **Tests**.
2. Type `MOSFET` into the search bar, then select **Pulse** in the Filters pane under Measurements.
3. Select the **MOSFET Pulse I-V Drain Family of Curves (pulse-vds-id)** test, then **Add** it to the project tree. Notice that the device is automatically added.



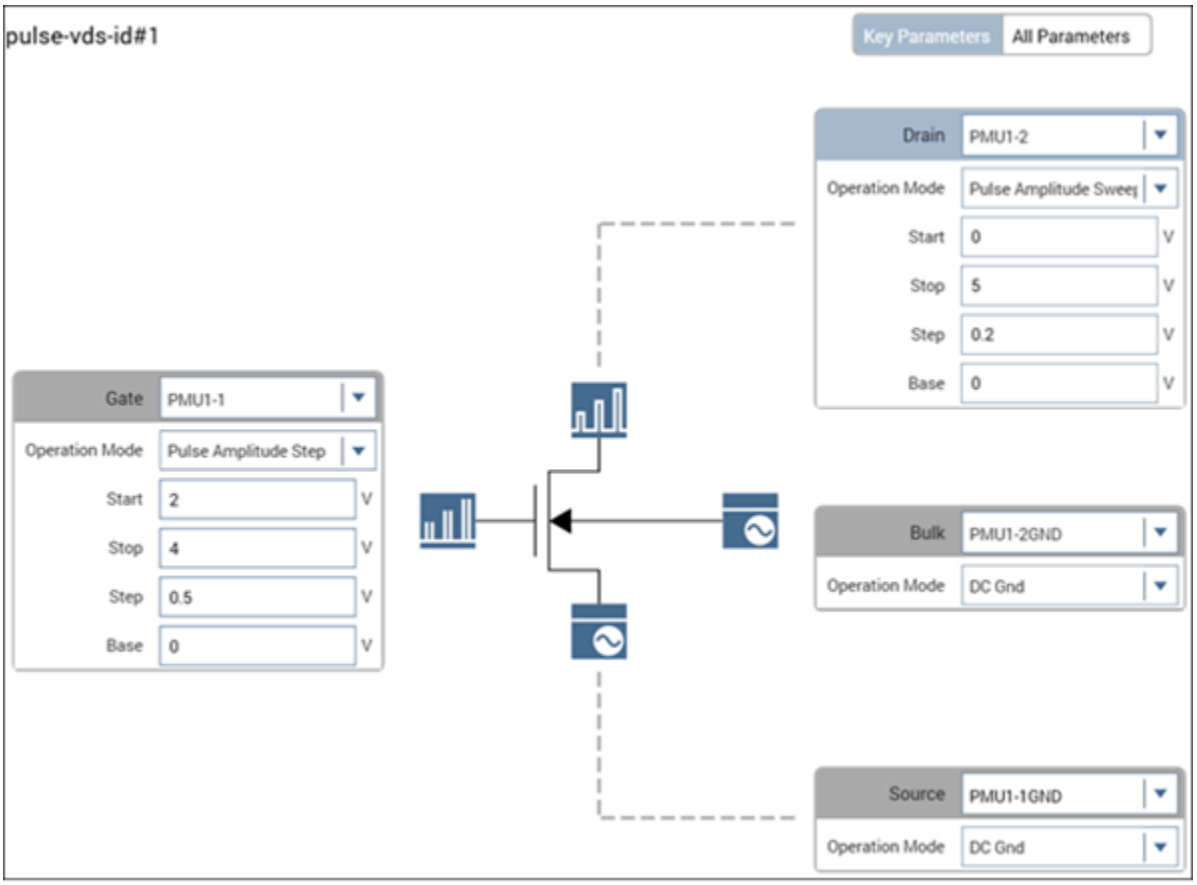
Configure the test

To configure the test:

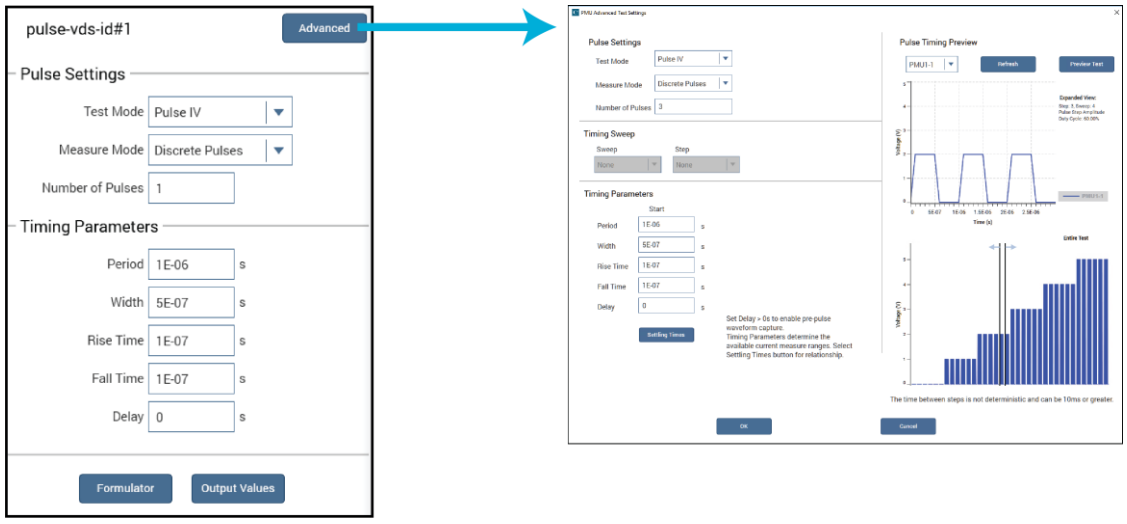
1. Select **Configure**.



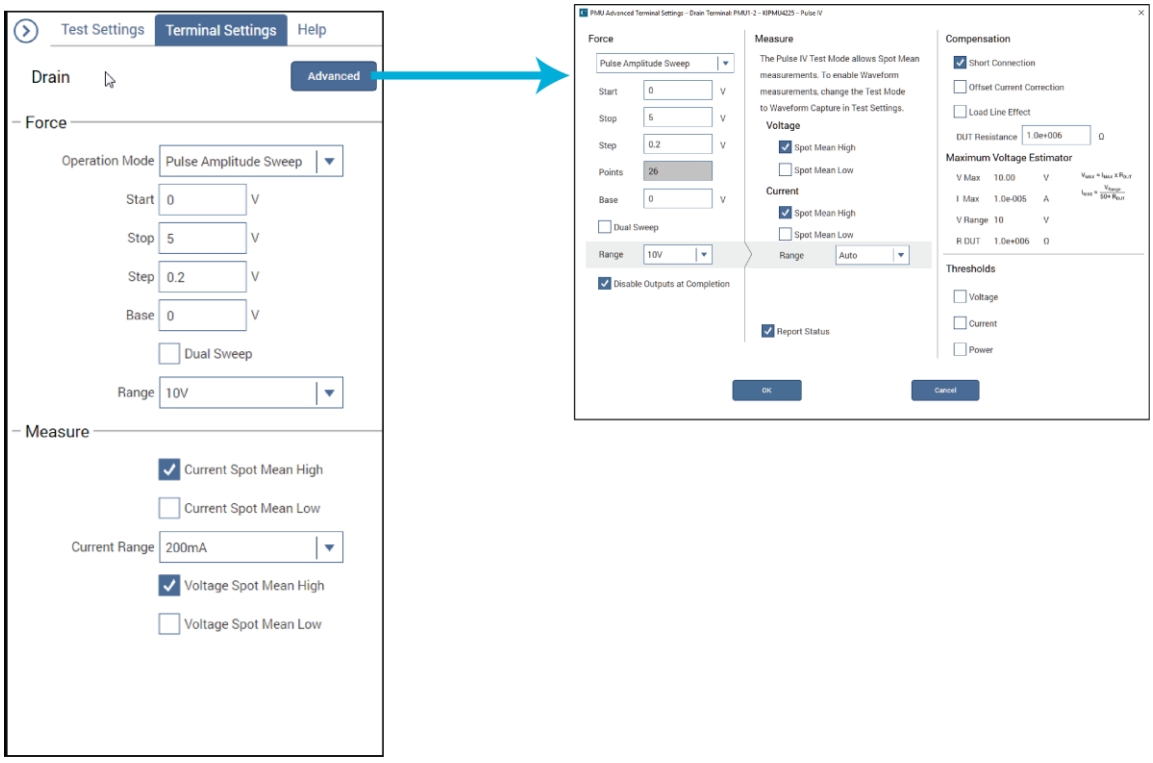
2. From the Key Parameters pane, adjust the pulse voltage sweep levels of PMU1-2 on the Drain terminal and the Pulse Step Voltage of PMU1-1 on the Gate terminal, as needed.



3. From the Test Settings pane and Advanced Test Settings dialog, adjust the Pulse Settings and Timing Parameters as needed.



4. From the Terminal Settings pane and Advanced Terminal Settings dialog, you can adjust the voltage source and current measurement parameters, as needed.

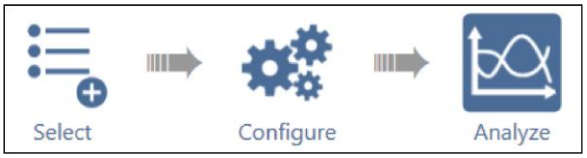


Run the test and analyze the results

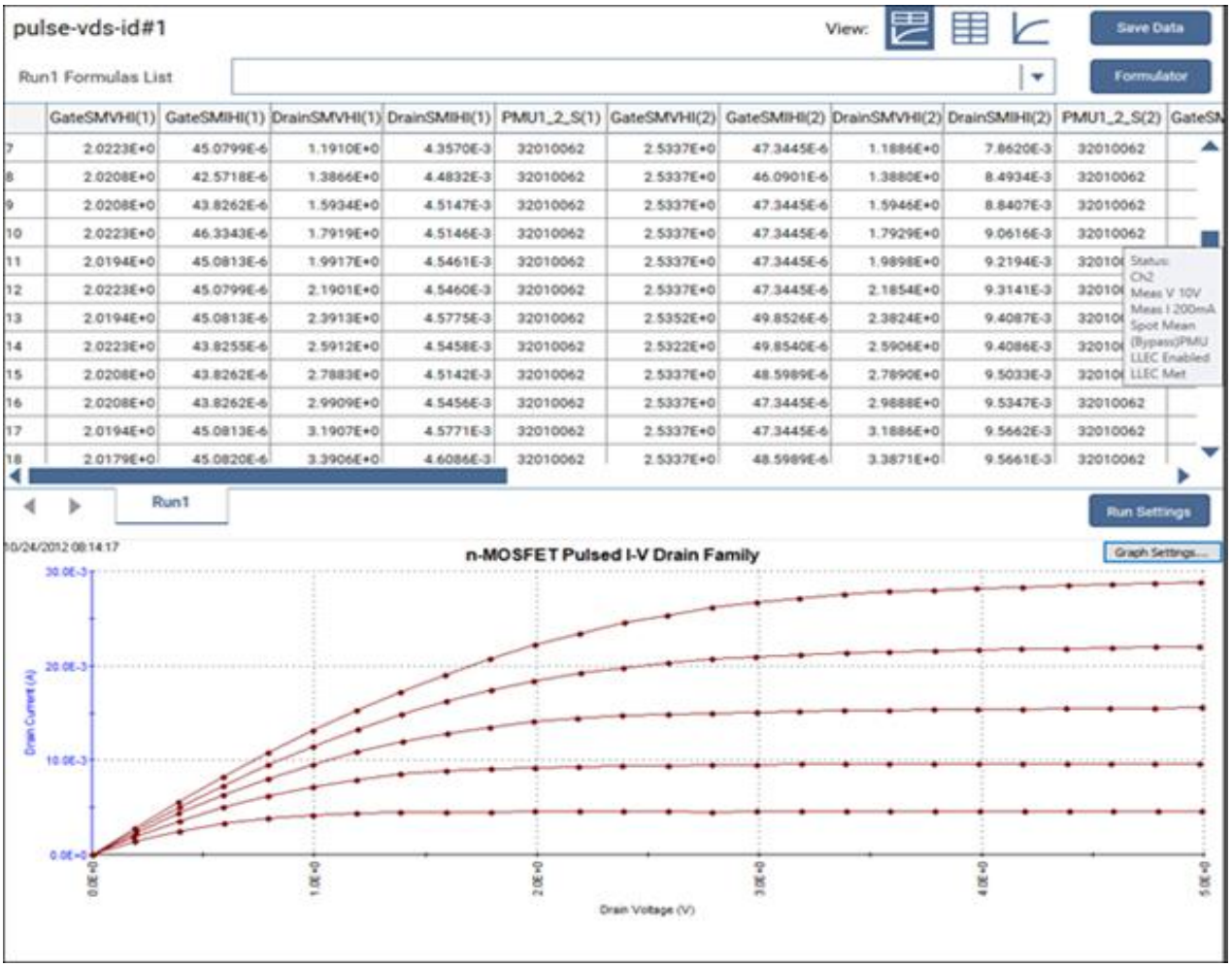
Select **Run** to execute the test.



When you run the project, you can select **Analyze**, shown in the following figure, to view test results in real time.



The data and the graph are displayed in the Analyze pane, as shown in the following figure.



Testing flash memory

Clarius includes several projects that you can use to test floating gate transistors (NOR, NAND) and other types of nonvolatile memory. This section describes the set up when using the following projects:

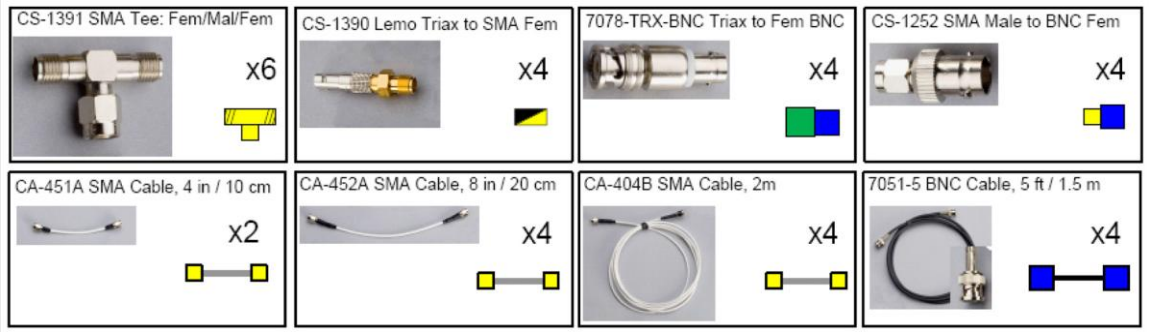
- Floating Gate Memory Flash Disturb Project (flashdisturb-nand)
- Floating Gate Memory Flash Endurance Project (flashendurance-nand)
- Floating Gate Memory NAND Characterization Project (flash-nand)

NOTE

For detailed information on using other memory projects, such as the Floating Gate Nonvolatile Memory Characterization Project (floating-gate-nvm-examples), refer to the application note (1KW-60638).

To use the flash memory tests, you need:

- Two pulse cards (four pulse channels).
- At least two SMUs. If your system does not include switching, it is best to have four SMUs to match the number of pulse channels to connect to a three- or four-terminal device. You can use 4200-SMUs, 4201-SMUs, 4210-SMUs, or 4211-SMUs with the SMU preamplifiers removed.
- Interconnecting cables and adapters, shown in the following table.
- 8 in.-lb torque wrench for tightening the SMA connections.



Recommended interconnect parts for flash memory testing

Qty.	Description	Comment	Keithley part number
6	SMA tee, female – male – female	Trigger, combine SMU and pulse channels	CS-1391
4	LEMO triaxial to SMA adapter	Adapt SMU Force output to SMA for signal interconnect	CS-1390
4	3-slot male triaxial to female BNC adapter	Convert BNC cabling to triaxial for prober or switching matrix connection	7078-TRX-BNC
4	SMA male to BNC female adapter	Adapt Tee to BNC for cabling from instrument to probe manipulators	CS-1252
2	10.8 cm (4.25 in.) white SMA cables	Interconnect for triggering	CA-451A
4	20.3 cm (8 in.) white SMA cables	Interconnect between pulse card and SMU signals	CA-452A
4	2 m (6.6 ft) white SMA cables		CA-404B
4	1.5 m (5 ft) BNC cable	Connect to probe manipulators	7051-5

This configuration permits independent source and measure for each terminal in a typical 4-terminal floating gate transistor.

Flash connection guidelines

All interconnects on instrument chassis are white SMA cables. Cables from the instrument to device are BNC coaxial, except for the direct SMU4 connection, which is black triaxial. Use triaxial to BNC adapters (if necessary) to connect to probe manipulators.

The trigger interconnects are white SMA cables. Cables from the instrument to device are BNC coaxial for the pulse card channels and triaxial for the SMUs. Use triaxial to BNC adapters (if necessary) to connect to probe manipulators.

To test on-wafer devices, there are various ways to connect the SMA cables to the probe manipulators. For the direct connect method or switch method, adapters convert the BNC cabling to the triaxial connector to be compatible with many types of probe manipulators.

Use the supplied torque wrench to tighten each connection as it is assembled. Always connect and torque adapter/cable assemblies before attaching the assembly to the instrument cards.

CAUTION

Nonaxial stress on the bulkhead connectors on the SMU or pulse cards could cause damage to the cards installed in the 4200A-SCS chassis. Pre-torque the connections to prevent this damage.

To remove the triaxial-to-SMA adapter from a SMU, pull on the knurled silver portion of the connector to release the latches from the SMU connector.

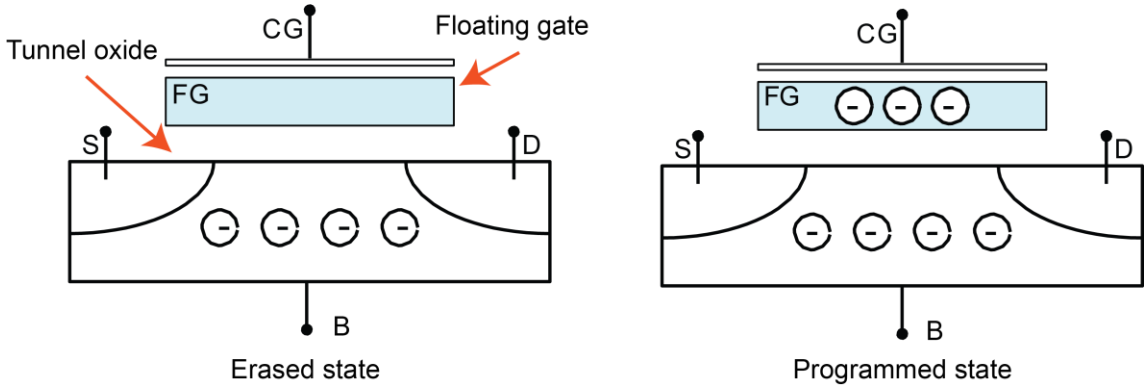
CAUTION

Failure to fully disengage the triaxial-to-SMA adapter latches may result in damage to the adapter and the SMU.

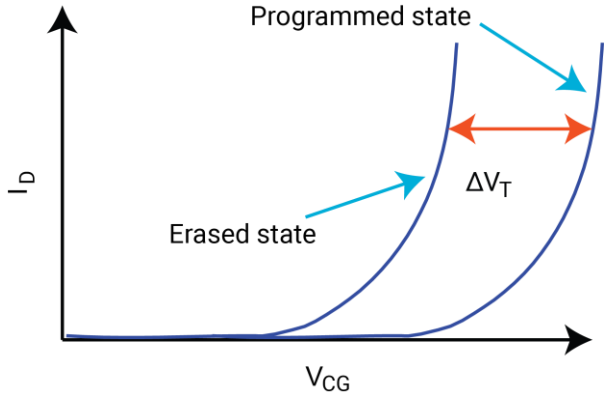
Programming and erasing flash memory

A floating gate (FG) transistor is a modified field-effect transistor with an additional floating gate. The FG transistor is the basic storage structure for data in nonvolatile memory. The floating gate stores charge, which represents data in memory.

The control gate (CG) reads, programs, and erases the FG transistor. The presence of charge on the gate shifts the voltage threshold (V_T) to a higher voltage, as shown in the following figure.



The control gate (CG) reads, programs, and erases the FG transistor. The presence of charge on the gate shifts the voltage threshold (V_T) to a higher voltage, as shown in the following figure.



The Flash transistors tests consist of two parts:

1. Pulse waveforms that program or erase the DUT
2. DC measurements are made to determine the state of the device

This implies switching between two conditions:

1. Pulse resources are connected to the DUT
2. Pulse resources are disconnected and the DC resources are connected to the DUT

The pulses are used to move charge to or from the floating gate. There are two different methods to move charge:

1. Tunneling
2. Hot charge injection (HCI)

The tunneling method is commonly known as Fowler-Nordheim (FN) tunneling, or quantum tunneling, and is a function of the electric potential across the tunneling oxide. HCI is considered a damage mechanism in nonfloating gate transistors. HCI is a method that accelerates charges by applying a drain-source field, and then the charges are directed into the floating gate by a gate voltage.

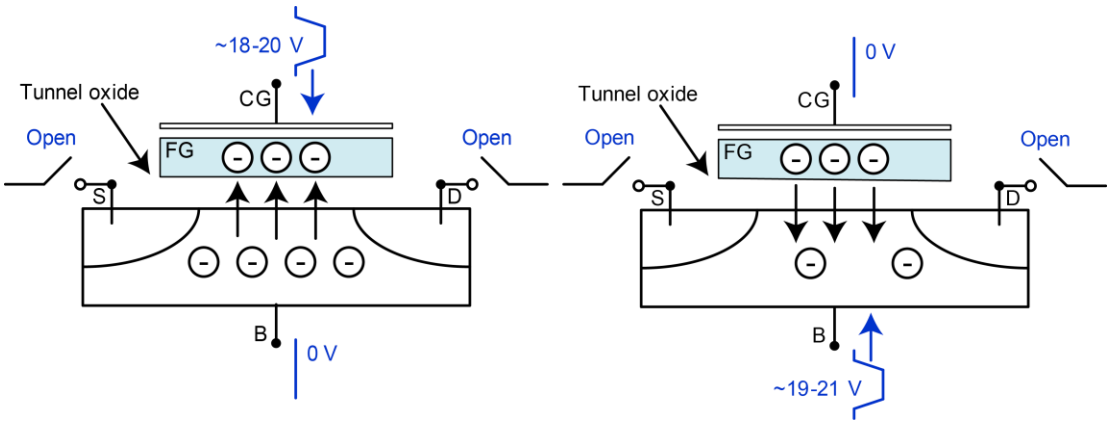
NOTE

The drain and source are not connected to any test instrumentation.

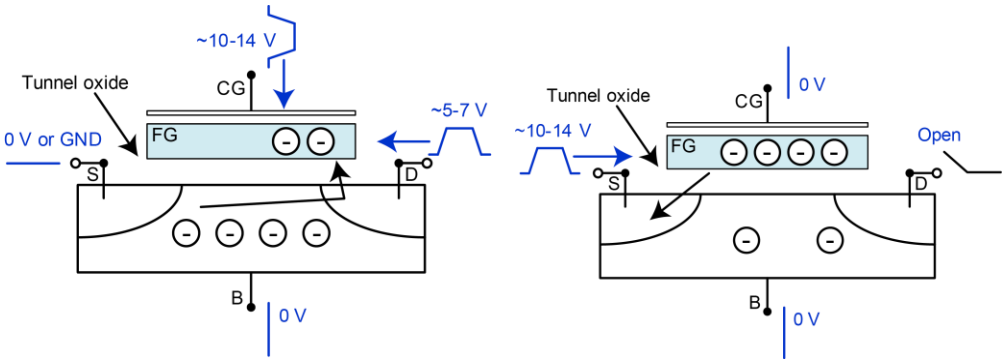
There are many other ways to provide similar electric fields and balance performance across a variety of parameters: program or erase speed, retention longevity, adjacent cell disturbance, endurance, and others.

The following figure shows examples of tunneling to move charge to and from the FG.

- The electric field and the preferred direction of electron flow are indicated by the black arrows.
- The signal applied to each device terminal is indicated by the blue text and blue features.



The following figure shows examples of moving charge using HCI. These conditions are examples with approximate voltage values. The pulse width and pulse height will vary depending on device structure and process details.

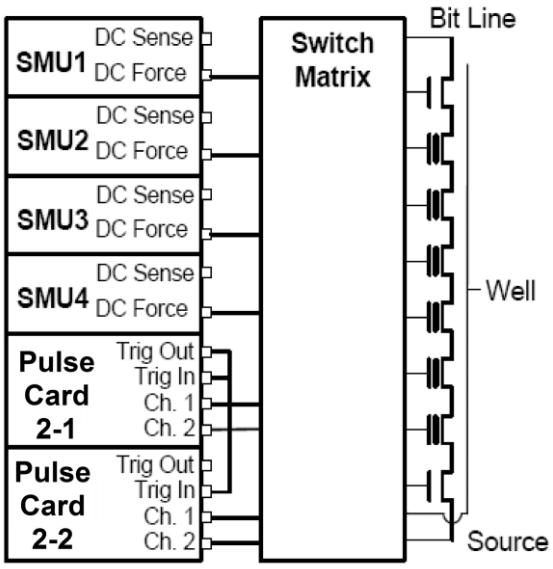


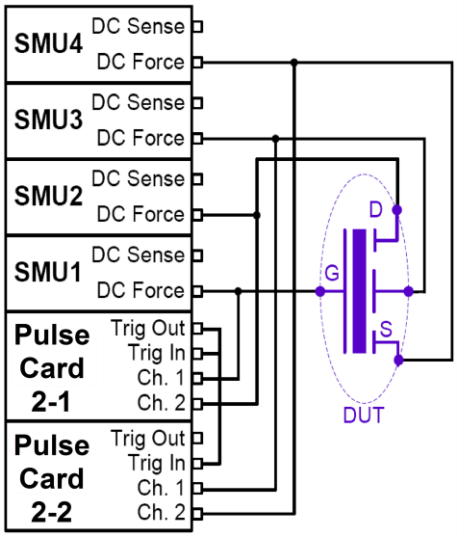
The flash projects support two methods for switching between the pulse and measure phases of the typical flash memory test.

The first is the typical method, using a switching matrix to route the pulse or DC signals to the DUT. Using the switching matrix is more complicated, but provides flexibility for certain tests and test structures that use arrays. The second method uses the on-card isolation relays on both the SMUs and the pulse cards to configure a simpler setup without the external switching matrix.

Because both the SMUs and the pulse cards have isolation relays on the cards, you can configure a simpler setup without the external switching matrix. The advantage of the simpler setup is lower cost. However, the switching matrix provides lower current measurement performance and the flexibility necessary for testing arrays of test structures.

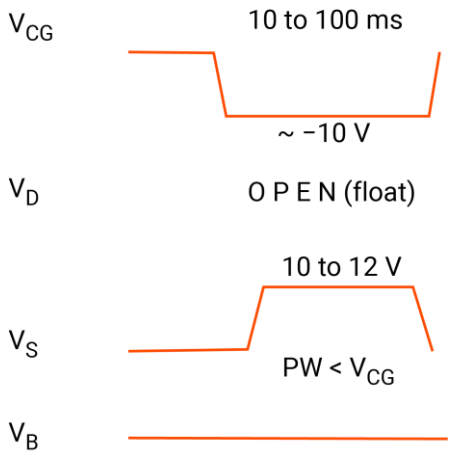
To determine the state of the device, you do a Vg-Id sweep, then perform a calculation to find the voltage threshold (V_T). The shift in V_T represents a change in the amount of charge stored in the floating gate, which indicates the state of the cell from fully programmed (**1**) to fully erased (**0**).



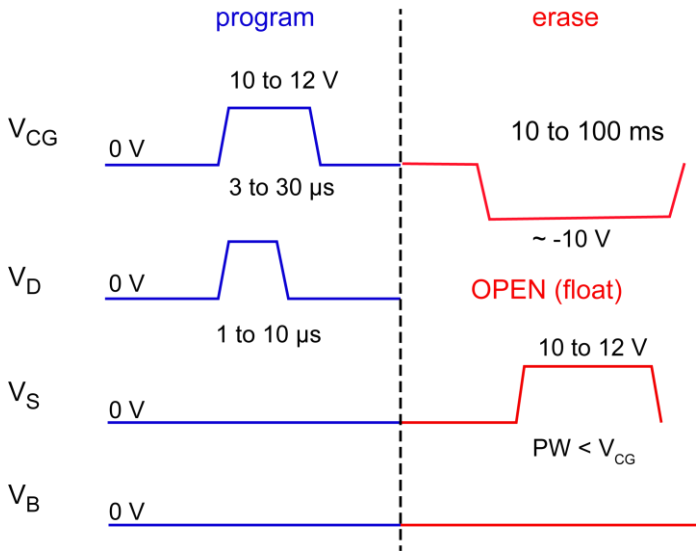


The pulse waveforms are a program pulse, an erase pulse, or a waveform made up of both program and erase pulses. All these waveforms are implemented by using the Segment Arb capability. For more information about waveforms, refer to Pulse Source-Measure Concepts (on page 84).

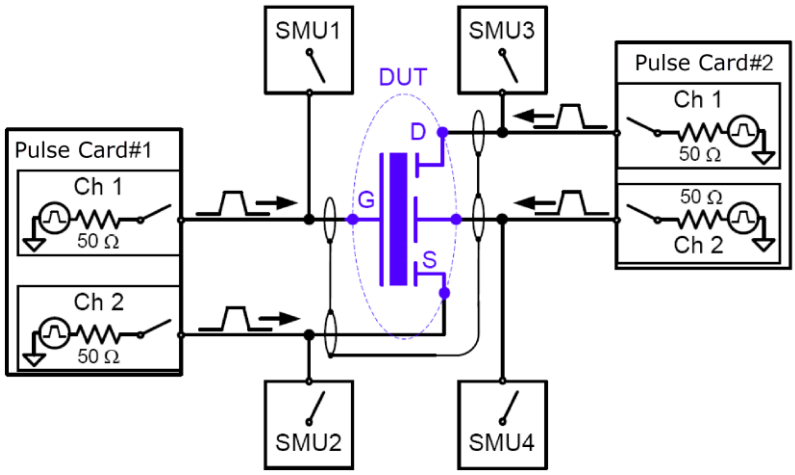
The following waveforms are program pulse waveforms for a floating gate DUT with separate pulse waveforms for the DUT gate, drain, source, and bulk.



The following waveforms are Program + Erase pulse waveforms for a floating gate DUT, with separate pulse waveforms for the DUT gate, drain, source, and bulk.



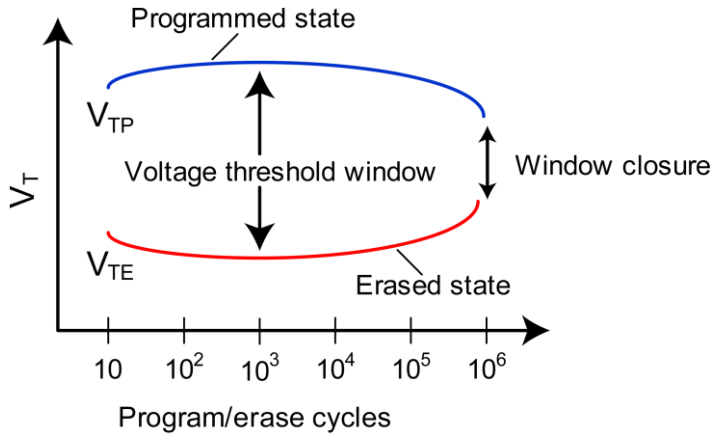
The block diagram for the flash setup is shown in the following figure. To reconfigure from the pulse stress to DC measure phases, activate the switches on the SMU and pulse cards. During the pulse program/erase phase, the relays in the pulse channels are closed and the relays in the SMUs are open. For the DC measure phase, the opposite is true.



Endurance testing

Endurance testing stresses the DUT with a number of Program+Erase waveform cycles, and then periodically measures both the voltage threshold in the programmed state (VTP) and the voltage threshold of the erased state (VTE). These tests to determine the lifetime of the DUT, based on the number of Program+Erase cycles withstood by the device before a certain amount of shift, or degradation, in either the VTP or VTE. The endurance test is performed a set number of program and erase cycles while periodically measuring V_T for both the programmed and erased state.

The following figure shows typical degradation on a NOR cell for both VTP and VTE as the number of applied program/erase cycles increases.



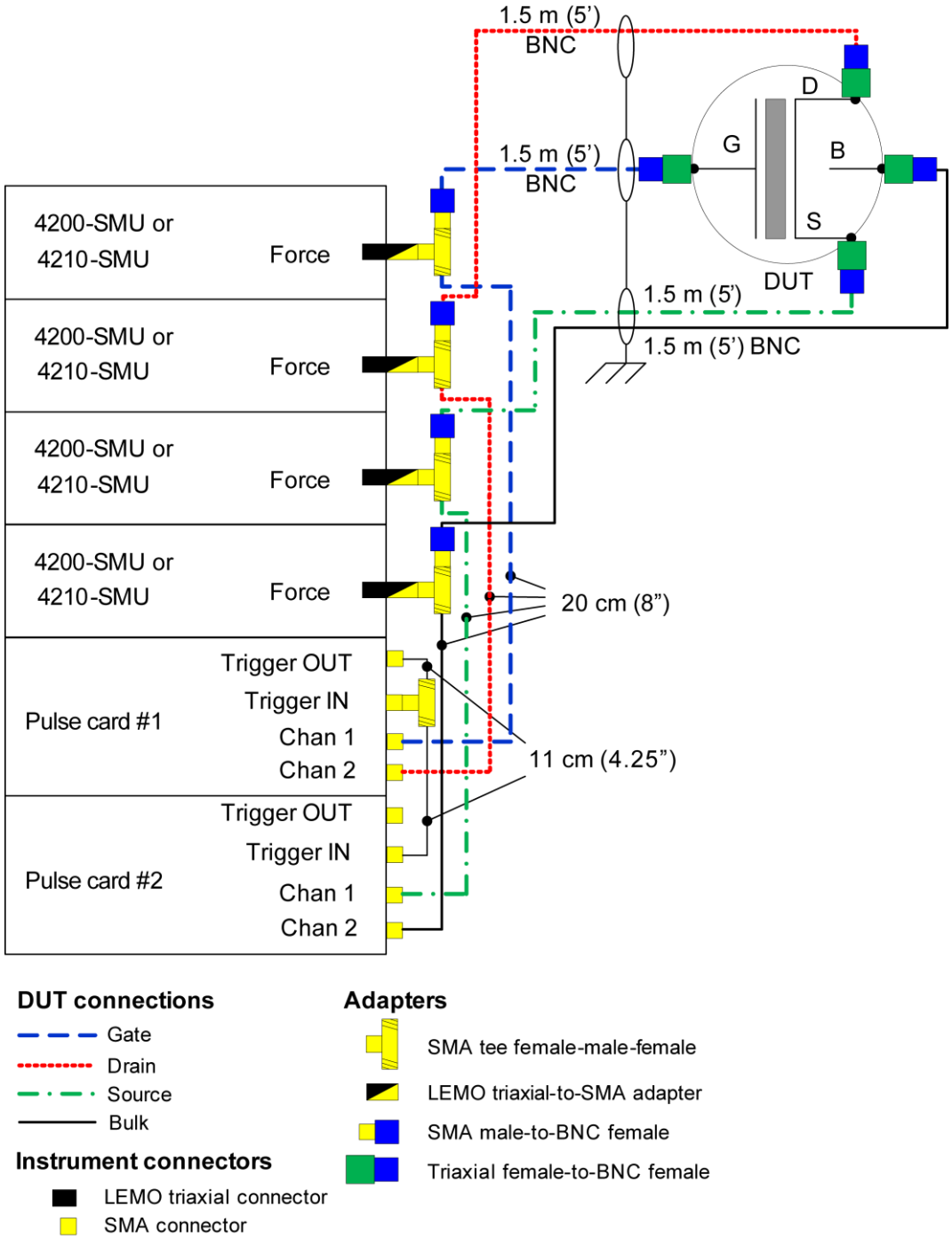
Connections for endurance testing - no switching matrix

For a direct connect configuration, the minimum number of pulse channels is equal to the number of DUT terminals that need to be simultaneously pulsed, including terminals that must change from connected to disconnected, or open, states for either the program or erase condition.

The following connection configuration does not require a switching matrix. It provides four channels of pulse and four SMUs to permit full characterization of single (nonarray) NVM DUT. This connection method is used for both the initial program/erase investigation and endurance testing of a directly-connected DUT.

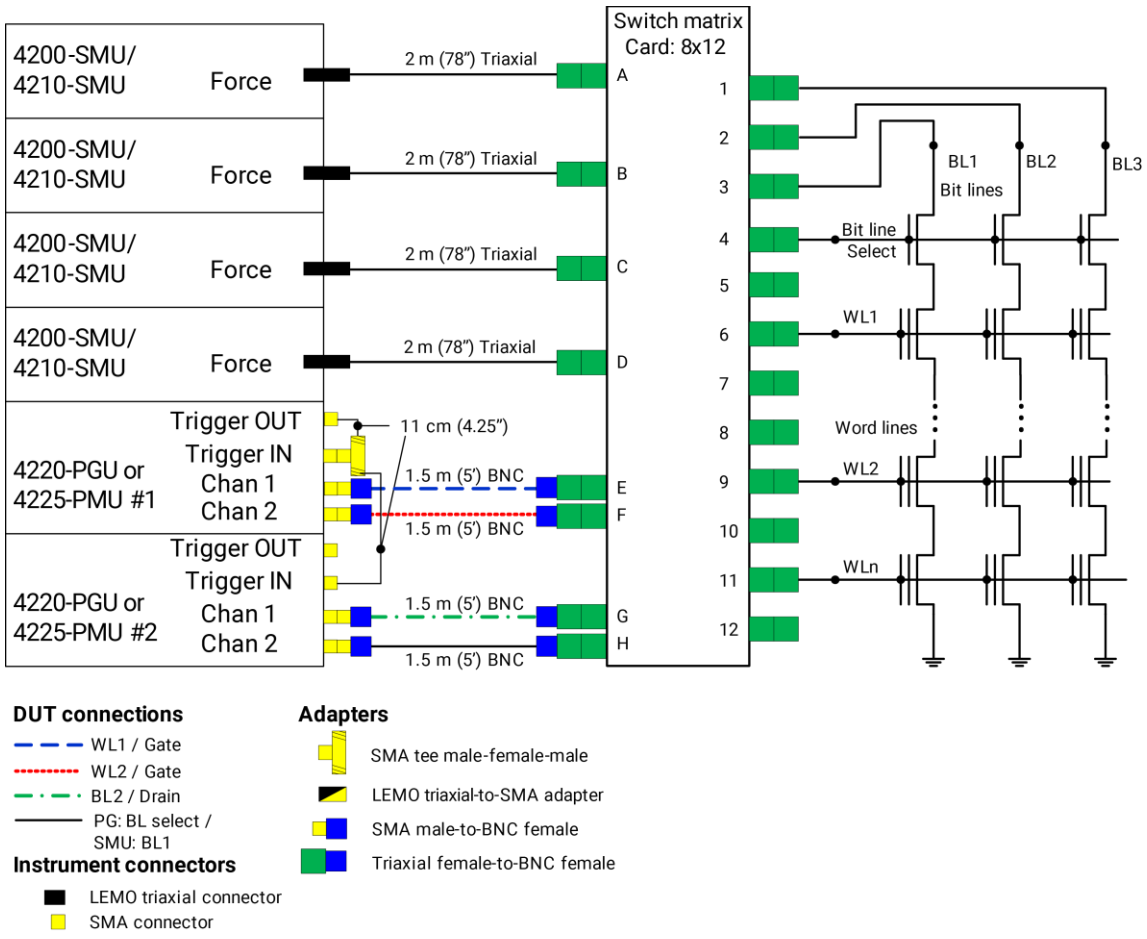
NOTE

All interconnects on instrument chassis are white SMA cables. Cables from the instrument to device are BNC coaxial. Use triaxial to BNC adapters if necessary to connect to probe manipulators.


1.5 m (5')
BNC
1.5 m (5')
BNC
D
G
B
S
DUT
1.5 m (5')
1.5 m (5') BNC
4200-SMU or
4210-SMU
Force
4200-SMU or
4210-SMU
Force
4200-SMU or
4210-SMU
Force
4200-SMU or
4210-SMU
Force
20 cm (8")
Pulse card #1
Trigger OUT
Trigger IN
Chan 1
Chan 2
11 cm (4.25")
Pulse card #2
Trigger OUT
Trigger IN
Chan 1
Chan 2
DUT connections
Gate
Drain
Source
Bulk
Instrument connectors
LEMO triaxial connector
SMA connector
Adapters
SMA tee female-male-female
LEMO triaxial-to-SMA adapter
SMA male-to-BNC female
Triaxial female-to-BNC female

Connections for endurance testing - switching matrix

A switching matrix is recommended for testing array test structures for endurance or disturb.



Disturb testing

The purpose of the Disturb test is to pulse stress a device in an array test structure, then make a measurement, such as V_T, on a device adjacent to the pulsed device.

The goal is to measure the amount of V_T shift in adjacent cells, either in the programmed or erased states, when a nearby device is pulsed with either a program, erase, or program and erase waveform.

The typical measurement is a V_T extraction based on a Vg-Id sweep, but you can configure any type of DC test. This test is similar to the endurance test, except that the pulsing and measuring are performed on adjacent devices.

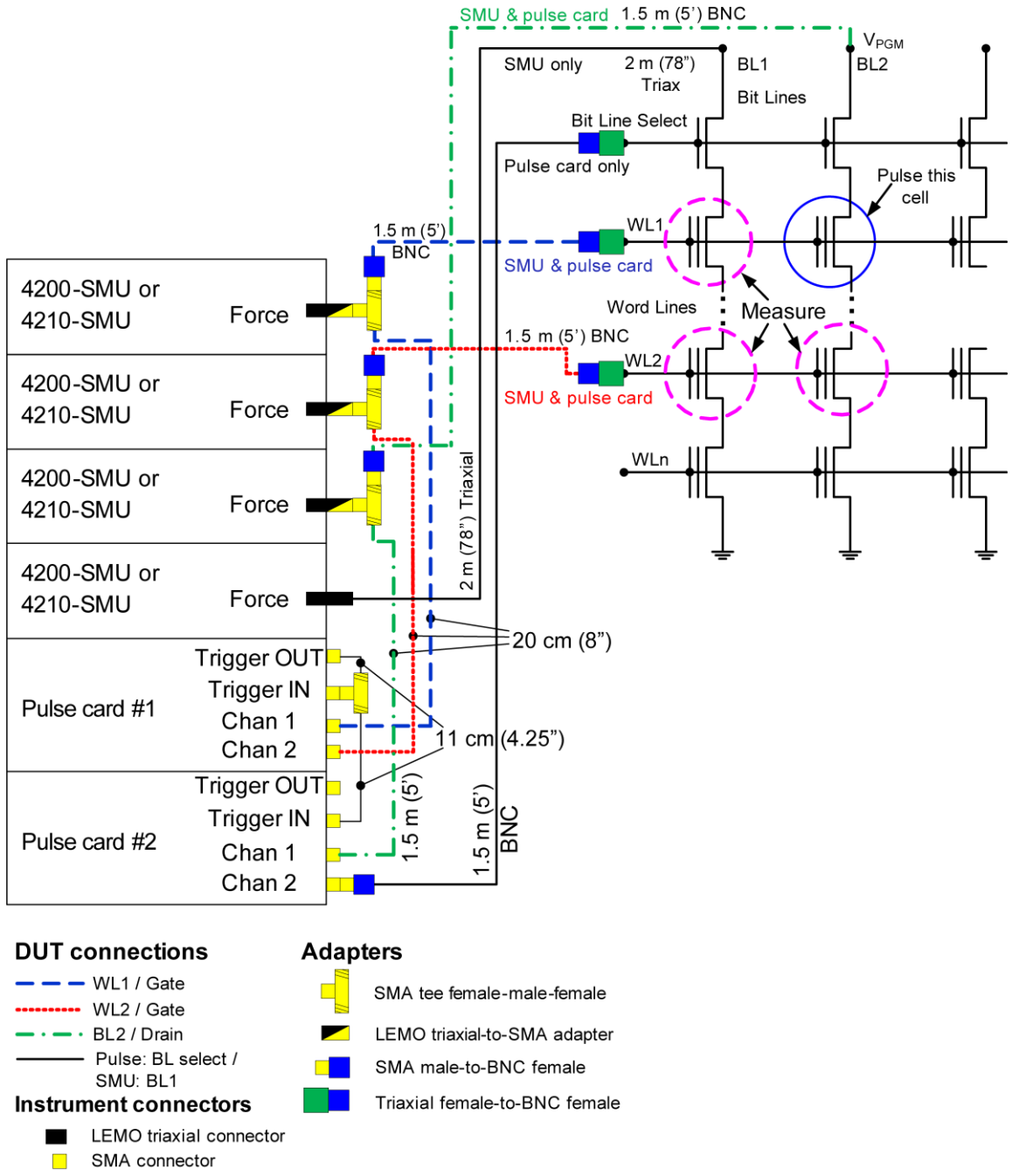
The solid-line blue circle indicates the cell to be pulse stressed, and the dotted-line red circles are the adjacent memory cells that will be disturbed by the stressing. This is the stress / measure process:

- **Initial test conditions:** SMU4 outputs a DC voltage to turn on the control devices for the array. This connects instrumentation at the top of array to the flash memory cells. SMU2 and SMU3 are set to output 0 V. This ensures that only the Cell 2 is turned on during pulse stressing.
- **Pulse stressing:** The output relay for SMU1 is opened, and the gate and drain of Cell 2 are pulse stressed by Pulse Card 1 (ch 1) and Pulse Card 2 (ch 1).
- **Disturbed cell testing:** The outputs for the pulse cards are turned off and their output relays are opened. SMU1 and SMU2 are then used to perform a DC Vg-Vd sweep on Cell 1 to determine V_T.

Connections for disturb testing

The following figure shows the connections used for disturb testing. A switching matrix is recommended for testing array test structures for both endurance or disturb. However, you can do a limited test of an array structure without using a switching matrix.

The following figure also shows connection to an array test structure, where one of the four SMU+pulse card channels was split. This provides a total of five test signals to provide the minimum necessary channels for the select pins (Bit Line Select, Bit Lines 1 and 2), to the pulse DUT (circled in blue), and the measure DUTs (circled in dashed purple). This configuration allows for pulsing one DUT while performing disturb measurements on the three DUTs labeled Measure. The fourth SMU in the figure is a dedicated connection to a bit line on the array DUT. During a pulse test, such as program or erase, this SMU outputs a DC voltage that provides power to the drain terminal of the first column of the array.

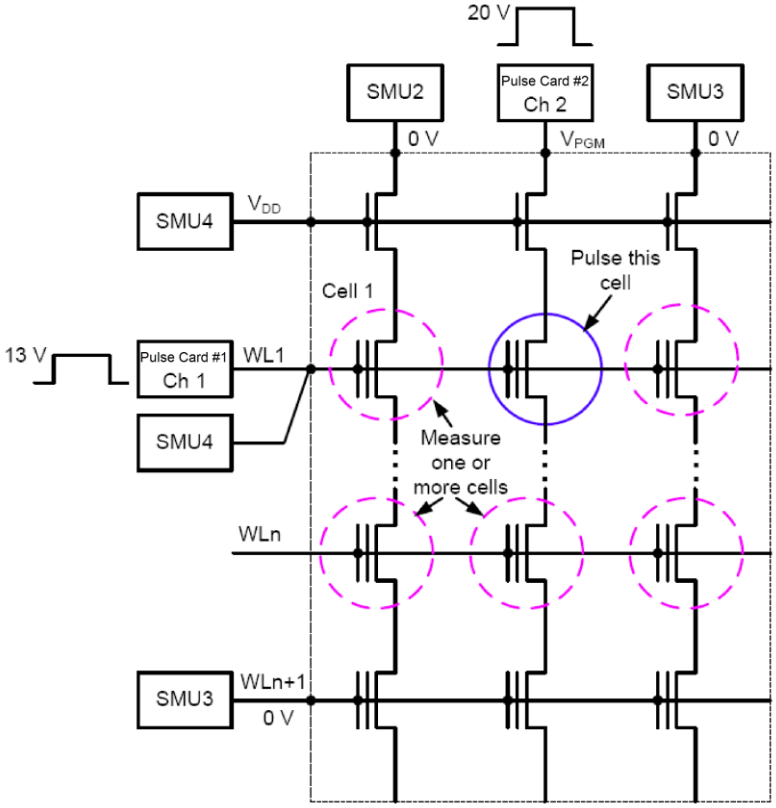

SMU & pulse card 1.5 m (5') BNC
SMU only
2 m (78") Triax
BL1
BL2
V_{PGM}
Bit Lines
Bit Line Select
Pulse card only
Pulse this cell
WL1
1.5 m (5') BNC
SMU & pulse card
Word Lines
Measure
1.5 m (5') BNC
WL2
SMU & pulse card
WLn
4200-SMU or 4210-SMU
Force
4200-SMU or 4210-SMU
Force
4200-SMU or 4210-SMU
Force
4200-SMU or 4210-SMU
Force
2 m (78") Triaxial
20 cm (8")
Pulse card #1
Trigger OUT
Trigger IN
Chan 1
Chan 2
11 cm (4.25")
Pulse card #2
Trigger OUT
Trigger IN
Chan 1
Chan 2
1.5 m (5')
1.5 m (5') BNC
DUT connections
WL1 / Gate
WL2 / Gate
BL2 / Drain
Pulse: BL select / SMU: BL1
Instrument connectors
LEMO triaxial connector
SMA connector
Adapters
SMA tee female-male-female
LEMO triaxial-to-SMA adapter
SMA male-to-BNC female
Triaxial female-to-BNC female

Using a switching matrix

A limitation of the no-switching, direct connect test configuration shown in the following figure is that only three devices can be measured. The test must be manually reconfigured or recabled to test other devices.

Without a switching matrix, the number of adjacent cells that can be measured is limited. Therefore, it is recommended that a switching matrix be used for disturb testing.

Using a switching matrix allows the flexibility of routing pulse and DC signals without having to make connection changes. Also, this type of structure uses a multipin probe card, which provides an additional opportunity for mapping test resources to DUT pins. For example, a SMU can be shared across multiple device terminals where the required voltage is the same.



Use KPulse to create and export Segment Arb waveforms

This example demonstrates how to create a program and erase waveform using the KPulse flash example file.

You will export the waveforms, which you can import into the Clarius Configure pane for the subsite when Segment Stress/Measure Mode is selected.

NOTE

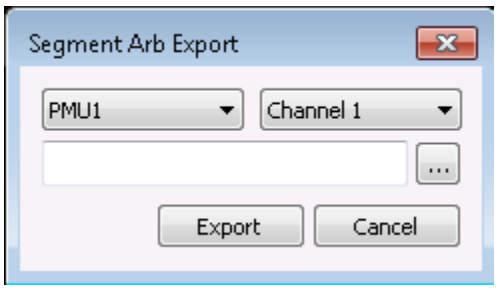
Each segment pulse waveform must have the same total time. The minimum programmed time for any segment is 20 ns (20E-9 s), but actual output waveform performance is determined by the channel output capability.

To use KPulse to create and export Segment Arb waveforms:

1. If they are open, close Clarius and KCon.
2. Open **KPulse**.
3. Select **File > Load Setup**.
4. Select **Kpulse_Flash_Example_01.kps**.
5. Select **Open**.
6. Select **Edit Segarb**. This opens the edit dialog for both channels. You can use copy and paste to copy information between the channels.
7. Note that the trigger is set to `1` in the first and fifth segments. These are the first segments in the program and erase pulses in a typical two pulse program/erase waveform. It is recommended that you set trigger to `1` for the first segment of each pulse in a waveform.
8. For each unique waveform, export each to a file as described below.

To export a Segment Arb waveform file:

1. Select **Tools**.
2. Select **Export Segment Arb** to open the Segment Arb Export dialog.



3. Select the pulse card and channel for the waveform to be exported.
4. Select **...**.
5. Locate the target folder.
6. Type a name for the file. The `.ksf` extension is added automatically.
7. Select **Open**.
8. Select **Export**.

Enter Segment Arb values into UTM array parameters

For tests that are based on user modules, such as the `program`, `erase`, and `fast-program-erase` tests, you need to define the Segment Arb waveforms by entering values into arrays for the tests. These tests are based on user modules. The Segment Arb waveforms have been partially pre-defined to reduce the number of parameters you need to enter.

NOTE

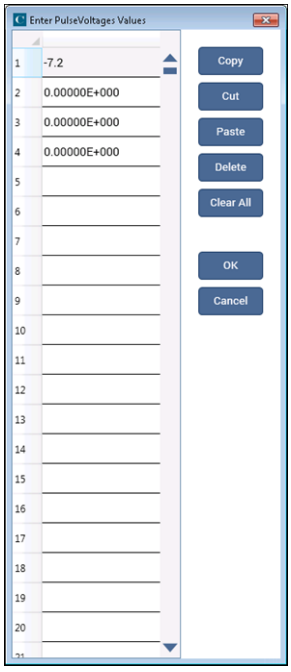
The sign of the PulseVoltages array determines whether the pulse is positive (usually for a `program` pulse) or negative (usually for an `erase` pulse).

NOTE

The number of parameters and number of pulse channels in the test must be the same. The period of each pulse waveform must be the same. If you accidentally enter a value in a field, delete the value (do not use 0).

To enter Segment Arb values:

1. In Clarius, select the project.
2. Select the test.
3. Select **Configure**.
4. Select the **Enter Values** button for each array. The Enter List Values dialog opens.



5. Enter the values.
6. Select **OK**.
7. For any stress and measure loop tests, such as `endurance` or `disturb`, use KPulse to define and export the waveform files, then import waveforms into the Subsite Stress Properties. Note that if the same waveform is required in the test and the Subsite Stress Properties, you must make sure the waveform information is the same for both.

Refer to the Clarius Help pane for information on the other parameters for each test.

Direct connections to single DUT

Cabling instructions for direct connections to a single DUT are below. Also refer to the figure in Connections for endurance testing - no switching matrix (on page 159).

NOTE

In all of the following steps, apply sufficient torque using an 8 in. lb. torque wrench.

These instructions are compatible with the following memory projects:

- `flash-nand`
- `flashdisturb-nand`
- `flashendurance-nand`

Make SMA cable connections to the pulse card:

1. Set up the 4200A-SCS.
2. Connect a 10.8 cm (4.25 in.) SMA cable to either end of an SMA tee.
3. Connect one of the SMA cables to TRIGGER OUT of the pulse card in the lowest numbered slot.
4. Connect the SMA tee to TRIGGER IN of the first pulse card.
5. Connect the SMA tee to TRIGGER IN of the second pulse card (which should be to the immediate left of the card in the lowest numbered slot).
6. If your system includes four pulse cards, connect the cables and tees as described above to the adjacent cards. There should be three SMA tees used to connect the triggering across the four cards.

Make SMA-to-BNC connections to the pulse and SMU cards:

1. Connect an SMA-to-BNC adapter to one of the sockets on an SMA tee.
2. Connect the tee to a triaxial-to-SMA adapter.
3. Connect a 20.3 cm (8 in.) SMA cable to the remaining SMA socket.
4. Connect a 1.5 m (5 ft) black BNC cable to the BNC connection.
5. Repeat these steps three times.
6. Use one of these cable assemblies to connect the SMA to CHANNEL 2 of the pulse card in the left-most slot (pulse card in the slot with the highest number).
7. Carefully insert the LEMO triaxial connector into the Force connector on the SMU in slot 4.
8. Route the BNC cable from SMU4 to the DUT terminal bulk connection. Connect a triaxial-to-BNC adapter, if necessary.
9. Connect the cable to the probe manipulator.
10. Use another one of the cable assemblies to connect the SMA to CHANNEL 1 of the pulse card in the left-most slot (pulse card in the slot with the highest number).
11. Carefully insert the LEMO triaxial connector into the Force connector on the SMU in slot 3.
12. Route the BNC cable from SMU3 to the DUT terminal source connection. Connect a triaxial-to-BNC adapter, if necessary.
13. Connect the cable to the probe manipulator.
14. Use another one of the cable assemblies to connect the SMA to CHANNEL 2 of the pulse card in the right-most slot (pulse card in the slot with the lowest number).
15. Carefully insert the LEMO triaxial connector into the Force connector on the SMU in slot 2.
16. Route the BNC cable from SMU2 to the DUT terminal drain connection. Connect a triaxial-to-BNC adapter, if necessary.
17. Connect the cable to the probe manipulator.
18. Use the remaining cable assembly to connect the SMA to CHANNEL 1 of the pulse card in the right-most slot (the pulse card in the slot with the lowest number).
19. Carefully insert the LEMO triaxial connector into the Force connector on the SMU in slot 1.
20. Route the BNC cable from SMU1 to the DUT terminal gate connection. Connect a triaxial-to-BNC adapter, if necessary.
21. Connect the cable to the probe manipulator.

Direct connections to array DUT for disturb testing

Cabling instructions for direct connections to an array DUT are below. These instructions are compatible with the following projects:

- `flashdisturb-nand`
- `flashendurance-nand`

NOTE

In all of the following steps, apply sufficient torque using an 8 in. lb. torque wrench.

Refer to the drawing in Connections for disturb testing (on page 162).

Make the SMA connections:

1. Set up the 4200A-SCS.
2. Connect a 10.8 cm (4.25 in.) SMA cable to either end of an SMA tee.
3. Connect one of the SMA cables to TRIGGER OUT of the pulse card in the lowest numbered slot.
4. Connect the SMA tee to TRIGGER IN of the first pulse card.
5. Connect the SMA tee to TRIGGER IN of the second pulse card (which should be to the immediate left of the card in the lowest numbered slot).
6. If your system includes four pulse cards, connect the cables and tees as described above to the adjacent cards. There should be three SMA tees used to connect the triggering across the four cards.

Make SMA-to-BNC connections to the DUT arrays:

1. Connect an SMA-to-BNC adapter to a 1.5 m (5 ft) black BNC cable.
2. Connect SMA end of the SMA-to-BNC adapter to CHANNEL 2 of the pulse card in the left-most slot (the pulse card in the slot with the highest number).
3. Route the BNC cable to the DUT array Bit Line Select connection. If necessary, use a triaxial-to-BNC adapter.
4. Connect the cable to the probe manipulator.
5. Insert the LEMO end of a black LEMO triaxial to 3-slot triaxial cable into the Force connection on the left-most SMU in slot 4.
6. Route the triaxial cable from SMU4 to the DUT array BL1 connection.
7. Connect the cable to the probe manipulator.

Make SMA-to-BNC connections to the pulse and SMU cards:

1. Connect an SMA-to-BNC adapter to one of the sockets on an SMA tee.
2. Connect the tee to a triaxial-to-SMA adapter.
3. Connect a 20.3 cm (8 in.) SMA cable to the remaining SMA socket.
4. Connect a 1.5 m (5 ft) black BNC cable to the BNC connection.
5. Repeat these steps twice.
6. Connect the SMA of one of the cable assemblies to CHANNEL 2 of the pulse card in the left-most slot (the pulse card in the slot with the highest number).
7. Carefully insert the LEMO triaxial connector into the Force connector on the SMU in slot 4.
8. Route BNC cable from SMU4 to the DUT array WL2 terminal. If necessary, use a triaxial-to-BNC adapter.
9. Connect the cable to the probe manipulator.
10. Connect the SMA of one of cable assemblies to CHANNEL 1 of the pulse card in the left-most slot (the pulse card in the slot with the highest number).
11. Carefully insert the LEMO triaxial connector into the Force connector on the SMU in slot 3.
12. Route the BNC cable from SMU3 to the DUT array BL2 connection. If necessary, connect a triaxial-to-BNC adapter.
13. Connect the cable to the probe manipulator.
14. Connect the SMA of one of the cable assemblies to CHANNEL 2 of the pulse card in the right-most slot (the pulse card in the slot with the lowest number).
15. Carefully insert the LEMO triaxial connector into the Force connector on the SMU in slot 2.
16. Route the BNC cable from SMU2 to the DUT array WL2 connection. If necessary, connect a triaxial-to-BNC adapter.
17. Connect the cable to the probe manipulator.
18. Connect the SMA of one of the cable assemblies to CHANNEL 1 of the pulse card in the right-most slot (the pulse card in the slot with the lowest number).
19. Carefully insert the LEMO triaxial connector into the Force connector on the SMU in slot 1.
20. Route the BNC cable from SMU1 to the DUT array WL1 connection. If necessary, connect a triaxial-to-BNC adapter.
21. Connect the cable to the probe manipulator.

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